GEOLOGICAL DEPENDENCE OF RESISTANCE FACTORS FOR DEEP FOUNDATION DESIGN

by

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ABSTRACT

This research addresses the issue of geological dependence of deep foundation designs resistance factors for driven pile and drilled shaft designs in different locations. For the proof, two sets of databases were used: one from the NCHRP 507 report and another driven pile and drilled shaft database with static load tests and soil profiles from the different locations in Vietnam were used to evaluate resistance factor design for different axial pile capacity prediction methods. Eight different static analysis methods were used for driven pile capacity evaluation: α- Tomlinson, α-API, λ, β, Nordlund, Thurman, Meyerhof SPT, and the Shmertmann SPT method. For drilled shafts the FHWA and Reese & Wight methods were used. In the analyses the correlations between Nspt and soil parameters were used. First Order Second Moment (FOSM), First Order Reliability Methods (FORM) and Monte Carlo simulations were used to evaluate the based analyses in the determination of the resistance factors (Φ). The following notable benefits were attained in this project: 1) Resistance factors are made available for the LRFD designs of driven piles and drilled shafts in Vietnam; 2) The results show that the resistance factors vary with methods, geomaterial types and geological locations; 3) The found resistance factors (Φ) for Vietnam give substantially greater factored capacities as compared to the 2012 AASHTO-LRFD recommendations

The form and content of this abstract are approved. I recommend its publication.

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1. Introduction

1.1 Problem Statement

Since AASHTO introduced the LRFD method to account for uncertainties associated with estimated loads and resistances, bridge superstructures have been designed using the LRFD method in most of the U.S. but the ASD method is still used for bridge foundation design in practice. This can lead to inconsistent levels of reliability between superstructures and substructures. In an effort to maintain a consist level of reliability, the Federal Highway Administration and AASHTO set a mandate date of October 1, 2007 after which all federal-funded new bridges including substructures shall be designed using the LRFD method. The deadline has passed but the implementation of LRFD methodology for bridge foundation design is still experiencing much difficulty since the resistance factors for deep foundation in the AASHTO LRFD specifications are based on commonly use design methods and nationwide general geologic conditions that do not address local specific conditions. For example, the driven pile and drilled shaft database used in the existing AASHTO code is based on the data gathered by the Federal Highway Administration (FHWA) and the Florida DOT and may not reflect the soil conditions of other states with less data. Therefore, the resistance factors recommended in the existing AASHTO code need to be verified before being applied to local soil condition and design practice. Each state or region has its unique geological formation and the methods of analysis given by the AASHTO LRFD specifications do not consider this variance formation. Direct application of the AASHTO LRFD specifications without considering geologic conditions in design methodology could lead to overly conservative or un-conservative design. Thus, the resistance factors must be developed for the unique soil types of the region, in which the piles are used, incorporating the many years of pile design and construction experience in that region.

1.2 Research Objective

The objectives of this study are two-fold

- To assess the geographical locations dependence of resistance factor from difference locations by separating the database in NCHRP 507 report (Paikowsky, et al., 2004) and using it to calibrate the resistance factors of deep foundations for each of the different locations.
- To assess the geographical locations dependence of resistance factors in Vietnam by calibrating the resistant factors of drilled shafts and driven piles for North, South and Central Vietnam

1.3 Research Approach

To achieve the research objectives, the following tasks are to be undertaken:

Task 1: Review the different design approaches used for bridge pile foundations including ASD and LRFD methods

Task 2: Review the design methods for the bearing capacity of driven piles and drilled shafts

Task 3: Review the methods for calibrating the resistance factors including fitting LRFD to ASD, First Order Second Moment Method (FOSM), First Order Reliability Method (FORM) and the Monte Carlo Simulation Method

Task 4: Separate the data from the NCHRP Report 507 by different locations and calibrate the resistance factors for deep foundations using dynamic and static analysis methods for each state and other locations in the world.

Task 5: Collect the top-down static load test for driven piles and drilled shafts and soil profiles from North, South and Central Vietnam and perform static analyses of pile bearing capacity for each test using the different analysis methods.

Task 6: Calibrate the resistance factors by using First Order Second Method (FOSM), First Order Reliability Method (FORM) and Monte Carlo Simulation Method

for the different static analysis methods, for the different pile types (drilled shafts and driven piles), and for the different geologic regions: North, South and Central Vietnam.

Task 7: Recommend the resistance factors for deep foundation design including driven piles and drilled shafts in Vietnam

Task 8: Compare the resistance factors for deep foundations for different locations in the U.S. and Vietnam the draw the conclusions as to the dependency of resistance factors on geological and geographical locations.

2. Literature Review

2.1 History of LRFD Development

From the early 1800s until the mid-1950s, the ASD approach has been used in the design of superstructures and substructures, in which all uncertainty in loads and material resistance is combined in a factor of safety or allowable stress. And after the mid-1950s, the LRFD approach has been developed for structural design with the objective of ensuring a uniform degree of reliability throughout the structure. The basic hypothesis of the LRFD is quantifying the uncertainties based on probabilistic approaches, which aims to achieve engineered designs with consistent levels of reliability. In the LRFD approach, different load types and combinations are multiplied by load factors while resistances are multiplied by resistance factors, and the factored loads should not exceed the factored resistances.

Until late 1970's the province of Ontario in Canada decided not to use AASHTO Standard Specification for Highway Bridges and started to develop its own bridge design code. It also decided to base its specification on probabilistic limit states. In 1979 the first edition of the Ontario Highway Bridge Design Code (OHBDC) was released to the design community as North America's first calibrated, reliability based limit state specification. In 1983, the second edition of the LRFD Code with Commentary was adopted in Ontario and its use became mandatory. This code was developed based on a reliability index of 3.5 for superstructure elements. The corresponding results of using similar reliability index in geotechnical engineering were not encouraging since the foundation elements generally became larger and the design became more conservative. The third edition of the Ontario Bridge Code with Commentary was adopted in 1992, and its use yields more reasonable design of

foundations but still more conservative than the previous AASHTO-based designs using ASD method.

Load and Resistance Factor Design (LRFD) was adopted by the American Association of State Highway and Transportation Officials (AASHTO) as an alternative method for the design of bridge superstructures in the early 1970's. At that time, allowable stress design was the only method available in AASHTO for the design of the bridge foundations. In 1987 AASHTO initiated a research program, administered by the National Cooperative Highway Research Program to develop LRFD method for Bridge Foundations (NCHRP 24-4), and concluded with a report NCHRP 343 (Barker, et al., 1991) "Manuals for the Design of Bridge Foundations". This research provided the basis for development of Section 10-Foundations and Section 11-Abutments, Piers and Walls in the 1994 AASHTO LRFD Specification. The research used a combination of calibration by fitting to ASD, and reliability theory. When reliability theory was used, they used First Order Second Moment (FOSM) method for preliminary analyses and First Order Reliability Method (FORM) for final analyses. The primary source of statistical data was from load test results provided by Reese and O'Neill (1988) and Horvath and Kenney (1979), for a total of 76 load test case histories. For piles in clay, the primary source of statistical data was from Sidi (1986). The number of pile load tests was not specifically reported, but was described as numerous. The specific source of statistical data for piles in sand, at least with regard to model error, was reported as from Robertson, et al. (1988) and Horvitz et al. (1981) load test data for the CPT method. For the Meyerhof SPT method in sand, Barker, et al. considered the bias and COV of the SPT test to be adequate for the development of model error statistics for this method. The resistance factor for the driven piles and drilled shafts from NCHRP 343 report are summarized in table 2.1 and 2.2

In 1997 the Florida Department of Transportation (FDOT) developed LRFD Code for their bridge design to deal with problems that they encountered in practice such as the unique characteristics of Florida geology- soft limestone formation, lime rock backfi1l materials which were widely used in south Florida- and the FDOT design methods of driven piles and drilled shafts developed through the FDOT research projects were not considered in the NCHRP 24-4 research project in developing the Resistant Factors . They performed calibrations of their current ASD practice to the LRFD format usiTO load combinations and load factors. The reliability index was calculated for the safety factor used in their ASD practice, and a target reliability index was chosen. The resistance factors were then calibrated for the target reliability index. This document makes an important contribution since it represents the thoughts of a progressive geotechnical organization in a transportation agency and it deals with their response to problems they saw with the LRFD Bridge Code. The result from NCHRP report are summarized in table 2.3, 2.4 and 2.5.

Withiam et al. (1998) authored a manual titled 'LRFD for Highway Bridge Substructures' published by the Federal Highway Administration (FHWA). Using this manual, FHWA offered a National Highway Institute (NHI) training course too many of the state DOT's in an effort to implement LRFD for foundation design.

Kyung Jun Kim et al. (2002) developed the resistance factors for the design of driven piles in North Carolina. The resistance factors were developed for the different static pile capacity analysis methods, for the different pile types, and for the unique geologic coastal and piedmont regions of the state. These factors were developed within the framework of reliability theory utilizing the Pile Driving Analyzer test and static load test data embodying the uncertainties associated with the capacity prediction model, the pile type and geometry, and the soil parameters. The form of probability distribution function describing the pile capacity is studied, and the

associated parameters are quantified. The first order reliability method (FORM) was used to evaluate the reliability index of the current design methods and to select the target reliability index, which was then used to develop the resistance factors.

Paikowsky et al. (2004) presented calibration resistance factor on deep foundations, published as NCHRP Report 507 for the development of LRFD for bridge foundation design, which became the basis for the 2007 AASHTO bridge design specification. This report gathered an extensive database of load test results for driven piles and drilled shaft and grouped the data in the pile load test database by soil type, resistance prediction method, the type of construction technique used and pile type to develop the statistics needed for the reliability analyses they conducted. Paikowsky, et al. (2004) treated the loads and the resistance as the random variables. They evaluated the distribution of the data, comparing the probability density graphs for the actual data to the theoretical normal and lognormal distributions, to choose which distribution function to use to characterize the data. In most cases, they found that the resistance data was lognormally distributed. Paikowsky, et al. (2004) fully relied upon the results obtained from reliability theory to determine resistance factors, though calibration by fitting to ASD was also checked. For reliability theory, they relied upon the results from the advanced reliability methods (i.e., Hasofer and Lind, 1974), which they termed "First Order Reliability Method (FORM)." While they compared the results from FORM to MVFOSM calibration results, they relied on the FORM results.

In 2004, the AASHTO-LRFD Oversight Committee conducted a survey among the State Departments of Transportation (DOTs) to monitor the degree of implementation of the LRFD approach for bridge substructure design (Moore, 2004), with a follow-up survey in 2005. The committee found that 12 states had fully

implemented the LRFD method for foundation design in 2004 and increased to 16 in 2005.

Nien-Yin Chang el al. (2006) sent a questionnaire to all state DOTs as part of the development of the LRFD strategic plan for foundation design practice in Colorado. Only 28 DOTs responded to the questionnaire, and revealed that less than 22% of the respondents had either implemented or began implementation of LRFD for bridge foundations, while the remaining 78% had not even attempted the LRFD implementation.

In 2007, the AASHTO-LRFD Oversight Committee updated the LRFD implementation survey in their progress report (Moore, 2007), which indicated that 44 states would have fully implemented the LRFD approach for all new bridges by the FHWA mandated deadline of October 1, 2007.

In 2008 the Iowa State University conducted the survey the current extent of LRFD implementation in the design of bridge foundations in the United States. Among the DOTs who responded as using the LRFD method for foundation design, 46% are using regionally calibrated resistance factors based on SLT database and reliability theory, 23% are using regionally calibrated factors by fitting to ASD, while 31% are using the geotechnical resistance factors as specified in the current AASHTO Specifications (2007)

In 2008 LADOT conducted the research to find the resistance factor for driven piles in soft Louisiana soils. Forty two precast prestressed concrete piles with different lengths and sizes that were loaded to failure were investigated in this study. Statistical analyses were conducted to evaluate the different pile design methods, including the static design method (α-method and Nordlund method), three different direct CPT design methods: Schmertmann method, De Ruiter and Beringen method,

and Bustamante and Gianeselli (LCPC) method, and dynamic measurement with signal matching analysis (CAPWAP) method. In addition, reliability analyses based on first order second moment (FOSM) method were conducted to calibrate the resistance factors (φ) for the different design methods needed in the LRFD design of single piles.

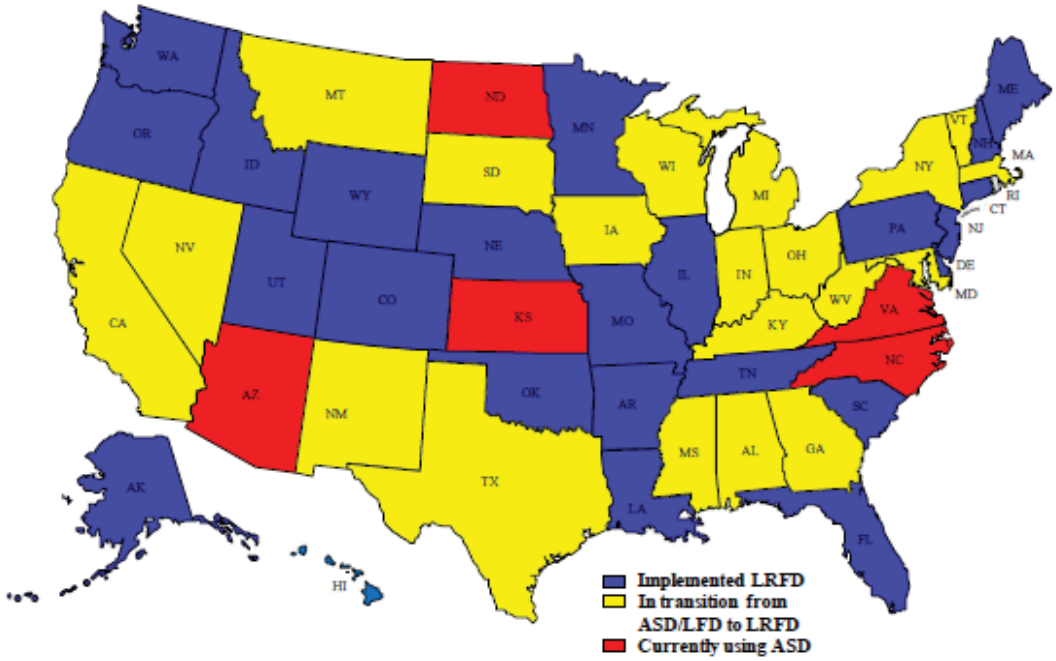


Figure 1.1 LRFD implementation for bridge foundations (after 2008 Iowa State survey)

In 2012 IDOT conducted research to calibrate regionally LRFD resistance factors for bridge pile foundations in Iowa based on reliability theory, taking into consideration the current local practices. The resistance factors were developed for general and Iowa's static analysis methods used for the design of pile foundations as well as for dynamic analysis methods and dynamic formulas used for construction control. The report showed a substantial gain in the factored capacity compared to the 2008 AASHTO-LRFD recommendations and gave comprehensive design tables and charts for implementation of the LRFD approach, ensuring uniform reliability and consistency in the design and construction processes of bridge pile foundations

2.2 Review of the Recommended Load Factors for Piles Designs

Table 2.1 Resistance Factor for Driven Piles for Estimating the Axial Geotechnical Pile Capacity Using Reliability-Based Calibration (modified after Barker, et al., 1991).

Pile Length (m)	β_T	ϕ Values by Method of Axial Pile Capacity Estimation						
		α		β	λ		CPT	SPT
		Type I	Type II		Type I	Type II		
10	2.0	0.78	0.92	0.79	0.53	0.65	0.59	0.48
30	2.0	0.84	0.96	0.79	0.55	0.71	0.62	0.51
10	2.5	0.65	0.69	0.68	0.41	0.56	0.48	0.36
30	2.5	0.71	0.73	0.68	0.44	0.62	0.51	0.38
Average ϕ		0.78		0.74	0.56		0.55	0.43
Selected ϕ		0.70		0.50	0.55		0.55	0.45

Type I refers to soils with Su < 50 kPa, Type II refers to soils with Su > 50 kPa

Table 2.2 Resistance Factors for Drilled Shafts for Estimating the Ultimate Axial Shaft Capacity Using Reliability-Based Calibration (Modified Barker, et al., 1991b)

Shaft Length (m)	β_T	ϕ Value by Method of Axial Shaft Capacity Estimation		
		Reese & O'Neill (1988) Shafts in Clay	Horvath & Kenney (1979) Shafts in Rock	Carter & Kulhawy (1987) Shafts in Rock
3	2.5	---	0.70	0.49
10	2.5	0.72	0.73	0.56
30	2.5	0.80	---	---
3	3.0	---	0.56	0.37
10	3.0	0.72	0.59	0.43
30	3.0	0.71	---	---
Average ϕ		0.74	0.65	0.46
Selected ϕ		0.65	0.65	0.55

Table 2.3 Reliability Index of Case Method Prediction (After McVay et al., 1998)

QD/QL	β		COV_R		λ_R		COV_{QD}	λ_D	COV_{QL}	λ_L	ASD FS
	EOD	BOR	EOD	BOR	EOD	BOR					
1	3.04	2.40	0.325	0.318	1.355	1.052	0.1	1.05	0.18	1.15	2.5
2	3.08	2.44	0.325	0.318	1.355	1.052	0.1	1.05	0.18	1.15	2.5
3	3.10	2.46	0.325	0.318	1.355	1.052	0.1	1.05	0.18	1.15	2.5
4	3.11	2.47	0.325	0.318	1.355	1.052	0.1	1.05	0.18	1.15	2.5
5	3.12	2.48	0.325	0.318	1.355	1.052	0.1	1.05	0.18	1.15	2.5
6	3.13	2.49	0.325	0.318	1.355	1.052	0.1	1.05	0.18	1.15	2.5
7	3.13	2.49	0.325	0.318	1.355	1.052	0.1	1.05	0.18	1.15	2.5
8	3.13	2.49	0.325	0.318	1.355	1.052	0.1	1.05	0.18	1.15	2.5
9	3.14	2.50	0.325	0.318	1.355	1.052	0.1	1.05	0.18	1.15	2.5

Table 2.4 Resistance Factor for Case Method Prediction (After McVay et al., 1998)

Q_D/D_L	Resistance Factor ϕ					
	EOD			BOR		
	β=2.0	β=2.5	β=3.0	β=2.0	β=2.5	β=3.0
1	0.85	0.70	0.58	0.66	0.55	0.46
2	0.81	0.67	0.56	0.64	0.53	0.44
3	0.79	0.66	0.54	0.62	0.52	0.43
4	0.78	0.65	0.54	0.61	0.51	0.42
5	0.77	0.64	0.53	0.61	0.51	0.42
6	0.77	0.64	0.53	0.60	0.50	0.42
7	0.77	0.63	0.53	0.60	0.50	0.41
8	0.76	0.63	0.52	0.60	0.50	0.41
9	0.76	0.63	0.52	0.60	0.50	0.41

Table 2.5 Comparison of Resistance Factors for Geotechnical Strength Limit State in Axial Loaded Piles and Drilled Shafts (After McVay et al., 1998)

Method/Soil/Condition		Resistance Factor		
		AASHTO (1994)	FDOT RESEARCH	
			Reliability	Fitting
Ultimate Bearing Resistance of Single Piles	Skin Friction and End Bearing: Sand SPT-method	0.45	0.65	0.70
	Skin Friction and End Bearing All Soils Load Test Pile Driving Analyzer	0.80 0.70	0.75 0.65	0.70 0.55
Drilled Shaft	All Soils	0.45-0.65	0.50-0.65	0.55

Table 2.6 Summary of Calibration Results for Bearing of Driven Piles, Dynamic Analyses

Condition /Resistance Determination Method	ASD FS Current Practice	ϕ from Calibration by fitting to ASD (Current Practice)	ϕ Reliability Theory, NCHRP 507	ϕ AASHTO 2007
Driving criteria established by static load test(s), production pile quality control by calibrated wave equation, or minimum driving resistance combined with minimum delivered hammer energy from the load test(s). For the last case, the hammer used for the test pile(s) shall be used for the production piles.	2.0	0.69	See Table 2.9	Values in Table 2.7 (0.55 to 0.90)
Driving criteria established by dynamic test with signal matching at BOR, of at least one production pile per pier, but no less than the number of tests per site provided in Table 2.8 Production pile quality control of remaining piles by calibrated wave equation.	2.25	0.61	0.65	0.65
Wave equation analysis at EOD without pile dynamic measurements or load test.	2.75	0.5	0.39	0.40
FHWA-Modified Gates pile formula at EOD.	3.5	0.39	0.38	0.40
Engineering News Record dynamic pile formula at EOD, with built in FS of 6 removed from formula.	3.5	0.39	0.26	0.10

Table 2.7 Relationship between Numbers of Load Tests Conducted per Site and ϕ (after Paikowsky, et al., 2004)

Number of Load Tests per Site	Resistance Factor, Site Variability		
	Low	Medium	High
1	0.80	0.70	0.55
2	0.90	0.75	0.65
3	0.90	0.85	0.75
$\geqslant 4$	0.90	0.90	0.80

Table 2.8 Number of Dynamic Tests with Signal Matching Analysis to be Conducted During Production Pile Driving (after Paikowsky, et al., 2004)

Site Variability	Low	Medium	High
Number of Piles Located within Site	Number of Piles with Dynamic Tests and Signal Matching Analysis Required (BOR)		
$\leqslant 15$	3	4	6
16-25	3	5	8
26-50	4	6	9
51-100	4	7	10
101-500	4	7	12
> 500	4	7	12

Table 2.9 Summary of Resistance Calibration Results for Driven Piles, Static Analyses.

Soil type	Design Method	Pile Type	ASD FS Used NCHRP 343	ϕ Calibration by fitting To ASD NCHRP 343	ϕ Reliability Theory NCHRP 343	ϕ AASHTO 96/2004	ϕ Reliability Theory, NCHRP 507	ϕ AASHTO 2007
Clay	α-Tomlinson method	concrete	2.5	0.61	0.70- 0.90	0.7	0.36	0.35
		pipe					0.25	
		H-Pile					0.40	
	λ-method	concrete	2.5	0.61	0.49-0.62	0.55	0.48	0.40
		pipe					0.24	
		H-Pile					0.37	
	β-method	concrete	2.5	0.61	0.68	0.5	0.32	0.25
		pipe					0.14	
		H-Pile					0.19	
Sand	Nordlund/ Thurman	concrete	-	-	-	-	0.42	0.45
		pipe					0.56	
		H-Pile					0.46	
	Meyerhof SPT	concrete	4.0	0.38	0.46-0.49	0.45	0.19	0.30
		pipe					0.31	
		H-Pile					0.42	
	Schmertn CPT	All piles	2.5	0.61	0.54-0.57	0.55	0.51	0.50
Rock	Canadian Geo. Society 1985	All piles	3.0	-	-	0.4	-	0.45

Table 2.10 Summary of Calibration Results for Drilled Shaft, Static Analyses

Soil type	Condition and Location	Design Method	ASD FS Used NCHRP 343	ϕ Calibration by fitting to ASD NCHRP 343	ϕ Reliability Theory NCHRP 343	ϕ AASHTO 96/98/04	ϕ from Reliability Theory, Recommended in NCHRP 507	ϕ AASHTO 2007
Clay	Side Resistance	α- method (Reese and O'Neill 1988)	2.5	0.612	0.72	0.65	0.24 to 0.28 recommended 0.30	0.45
	Base Resistance	Total Stress (Reese and O'Neill 1988)	2.75	0.55		0.55	0.24 to 0.28 recommended 0.30	0.40
Sand	Side Resistance	method (Reese and O'Neill 1988)	2.5	0.61	-	-	0.25 to 0.73 recommended 0.40	0.55
	Base Resistance	(Reese and O'Neill 1988)	2.75	0.55		-	0.25 to 0.73 recommended 0.40	0.50
Mixed Soil	Side and Base Resistance sand/clay	Reese and O'Neill 1988	-	-	-	-	0.52 to 0.69 recommended 0.50 to 0.70	0.55 for side, 0.50 for base
	IGM's	O'Neill and Reese 1999	-	-	-	-	0.57 to 0.65	0.60 for side, 0.55 for base
Rock	Side Resistance	Carter and Kulhawy (1988)	2.5	0.61	0.43	0.55	0.45 to 0.49	0.50
		Horvath and Kenney (1979)	2.5	0.61	0.73	0.65	-	0.55
	Base Resistance	Canadian Geotechnical Society (1985)	3.0	0.51	-	0.50	-	0.50
		Pressure Method (Canadian Geotechnical Society 1985)	3.0	0.51	-	0.50	-	0.50
Bearing	Block failure	Clay	2.3	0.67	-	0.65	-	0.55

Table 2.11: Summary of the reported LRFD resistance factors, sorted according to different pile types, static analysis methods, and soil types (after 2008 Iowa State survey)

State	Pile Type	Static analysis methods		Resistance Factors		
		Cohesive	Cohesionless	Sand	Clay	Mixed
AK	CIDH(1)	α-method	SPT-method	0.45	N/A	N/A
CA*	Steel H-piles	CPT-method	Nordlund	0.45	0.35	N/A
CO	CIDH	SPT-method	SPT-method	0.1	0.9	0.5
CT*	Prestressed	Iowa blue book	Iowa blue book	0.65	0.65	0.65
FL*	CIDH	CPT-method	Nordlund	0.65	0.65	0.65
HI	Steel H-piles	β-method	β-method	0.65	0.65	0.65
IA*	Steel H-piles	Iowa blue book	Iowa blue book	0.725	0.725	0.725
ID*	Steel H-piles	β-method	SPT-method	0.45	0.45	0.45
IL	Open- pipe	α-method	Nordlund	0.7	0.7	0.7
MA*	Open end pipe	Iowa blue book	Nordlund	0.65	0.65	0.65
NH*	Closed-pipe	α-method	Nordlund	0.45	0.35	N/A
NJ*	CIDH	α-method	Nordlund	0.45	0.35	0.4
NM*	Steel H-piles	β-method	Nordlund	0.35	0.45	N/A
NV	Steel H-piles	α-method	Nordlund	0.35	0.25	N/A
PA*	Steel H-piles	β-method	Nordlund	0.5	0.5	0.5
PA	Steel H-piles	λ-method	SPT-method	0.45	0.55	0.55
UT*	Steel H-piles	α-method	Nordlund	0.5	0.7	0.7
WA	Steel H-piles	Iowa blue book	Iowa blue book	0.5	0.5	0.5
WY	Steel H-piles	CPT-method	Nordlund	0.45	0.35	0.35

*State DOTs having pile static load test database; (1) CIDH: Cast-In-Drilled-Hole Shafts;

2.3 ASD versus LRFD

According to surveying from Paikowsky et al. (2004) the averaging the responses for driven piles and drilled shafts, about 90% of the respondents used ASD,

35% used AASHTO Load Factor Design (LFD), and 28% used AASHTO Load and Resistance Factors Design (LRFD).

2.3.1 Allowable Stress Design (ASD)

The design of deep foundations has traditionally been based on the allowable stress design (ASD), which involves applying a factor of safety (FS) to account for uncertainties in the applied loads and soil resistance. The magnitude of FS depends on the importance of the structure, the confidence level of the material properties, and design methodology. From NCHRP 507 report, among the respondents using ASD to evaluate capacity, 95% used a global safety factor ranging from 2.0 to 3.0, depending on construction control and 5% used partial safety factors of 1.5 to 2.0 for side friction (3.0 for drilled shafts) and 3.0 for end bearing (2.0 to 3.0 for drilled shafts).

For the strength limit state in ASD, the estimated loads (or stresses) $\sum Q_i$ are restricted as shown bellow:

$$\frac{R_n}{FS} \geq \sum Q_i \tag{2.1}$$

where: R_n = Nominal resistance

F_s = Factor of safety

$\sum Q_i$ = Load effect (dead, live and environmental loads).

For the Service Limit State, un-factored loads are used to calculate deformations, and these deformations are compared to the maximum tolerable values.

The advantage of ASD is its simplicity but the shortcomings of this approach are:

- Does not account for variability of loads and resistances.
- Does not embody a reasonable measure of strength
- The FS is applied only to resistance and selection of a FS is subjective, and does not provide a measure of reliability in terms of probability of failure.

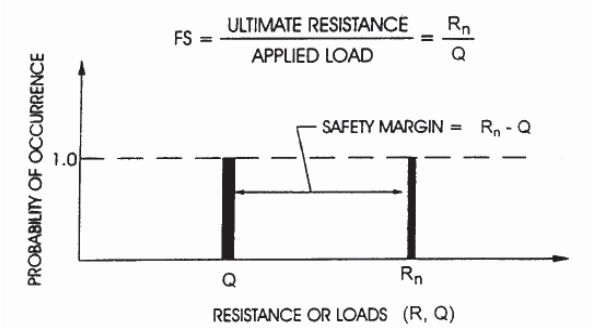


Figure 2.1 Factor of Safety

Table 2.12. Factor of Safety on Ultimate Axial Geotechnical Capacity Based on Level of Construction Control (AASHTO, 1997).

Basis for Design and Type of Construction Control	Increasing Design/Construction Control				
Subsurface Exploration	X	X	X	X	X
Static Calculation	X	X	X	X	X
Dynamic Formula	X				
Wave Equation		X	X	X	X
CAPWAP Analysis			X		X
Static Load Test				X	X
Factor of Safety (FS)	3.50	2.75	2.25	2.0	1.90

Table 2.13 Factors of Safety on Ultimate Geotechnical Capacity Based on Design Life and Level of Construction Control (Reese and O'Neill, 1988)

Design Life (Type of Structure)	Required Minimum Factor of Safety (FS)[1]		
	Poor Quality Control	Normal Quality Control	Good Quality Control
200 to 500 years (large bridges & monumental structures)	3.5	2.3	1.7
75 to 100 years (typical rail & road bridges & large buildings)	2.8	1.9	1.5
25 to 50 years (industrial buildings)	2.3	1.7	1.4

(1) Assumes good-quality geotechnical information and reliable model.

2.3.2 Load and Resistance Factor Design (LRFD)

The LRFD specifications as approved by AASHTO (AASHTO, 1994/2007) recommend the use of load factors to account for uncertainty in the loads, and resistance factors for the uncertainty in the material resistances. This safety criterion can be written as:

$$\Phi R_n \geq \eta \sum \gamma_i Q_i \tag{2.2}$$

where:

R_n = Nominal resistance,

η = Load modifier to account for effects of ductility, redundancy and operational importance. The value of η usually ranges from 0.95 to 1.00. In this research, $\eta = 1.00$ is used

Q_i = Load effect

γ_i = Load factor. Based on current AASHTO recommendation, the following factors are used

$\gamma_D = 1.25$ for dead load

$\gamma_L = 1.75$ for live load

Φ = Resistance factor--Usually ranges from 0.25 to 0.8.

For driven piles and drilled shaft, we have

$$\Phi R_n \geq \sum 1.25\, Q_D + 1.75\, Q_L \tag{2.3}$$

If different resistance factors are used for tip and side resistance, then

$$\Phi_s R_s + \Phi_p R_p \geq \sum 1.25\, Q_D + 1.75\, Q_L \tag{2.4}$$

where: R_s = Side resistance

R_p = Tip resistance

Φ_s; Φ_p= Resistance factors for side and tip resistance, respectively.

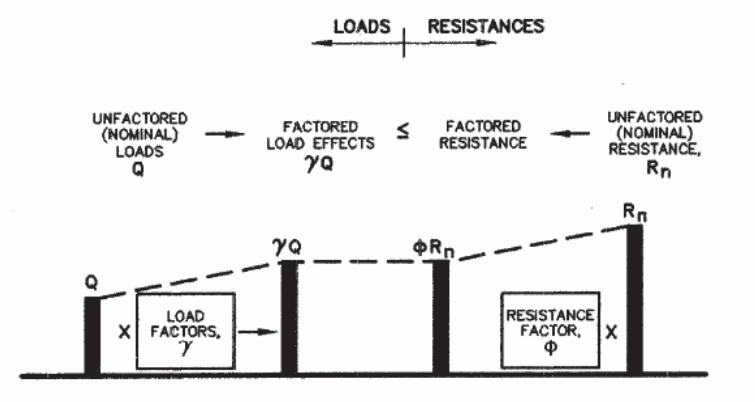


Figure 2.2 LRFD Design Approach

The LRFD Approach Has The Following Advantages:

- It accounts for variability in both resistance and load.
- It provides more consistent levels of safety in the superstructure and substructure as both are designed using the same loads for known probabilities of failure.
- Using load and resistance factors provided in the code, no complex probability and statistical analysis is required.

The Limitations of The LRFD Approach Include:

- Requires a change in design procedures for engineers accustomed to ASD.
- Resistance factors vary with design methods and are not constant.
- Rerequires the availability of statistical data and probabilistic design algorithms.

3. Axial Pile Capacity Prediction Methods

3.1. Axial Loading Capacity of a Driven Pile

The ultimate resistance of a pile, R_{ult} (or R_n-Norminal resistance), is given below:

$$R_{ult} = R_P + R_s \quad (3.1)$$

where: pile tip resistance $R_p = q_p A_p$,

pile side resistance $R_s = \sum q_{si} \Delta z_i a$,

q_p = unit tip resistance.

q_s = unit side resistance, which is regarded as constant along segment Δz_i of the pile.

a= perimeter of the pile's shaft.

A_p = area of the tip of the pile.

According to surveying from Iowa State (2008), the most common static analysis method used for piles in cohesive soils is the α-method at 42% (Tomlinson, 1957; API, 1974). About 32% respondents claim to be using the β-method (Esrig and Kirby, 1979), 11% use the CPT method (Nottingham and Schmertmann, 1988), and 9% follow the λ-method (US Army Corps of Engineers, 1992). The most popular static analysis method for piles in cohesionless soils is the Nordlund's method at 63% (Nordlund and Thurman, 1963). About 40% of the respondents use the SPT method (Meyerhof, 1976/1981).

Semi-empirical Methods

α-method- Total stress static method of analysis for estimating the ultimate unit side resistance, q_s, as a function of the undrained shear strength, Su, of cohesive soil

β-method - Effective stress method of analysis for estimating q_s in soil as a function of the effective overburden pressure

λ-method - Effective stress method of analysis for estimating q_s in soil as a function of the passive effective lateral earth pressure

In-Situ Methods

SPT-method - developed by Meyerhof (1976/1981) which correlates q_s and q_p with the SPT blow count for cohesionless soils and by Schmertmann for all soil types and rock

CPT-method - developed by Nottingham and Schmertmann (1975) which correlates q_s and q_p with CPT results for all soil type soils

Methods Based on Field Testing of Pile

PDA Method - A method for estimating total load capacity based on monitored performance of driven piles and wave equation analyses

Static Load Test - A method for estimating total load capacity based on tests (ASTM, 1996) representative of pile, load and subsurface conditions expected for the prototype piles

3.1.1. Side Resistance in Cohesive Soil

In cohesive soil, the side resistance of a pile is usually predicted using the undrained shear strength, S_u, or the over-consolidation ratio, OCR. This section reviews different methods predicting the side resistance in cohesive soil.

3.1.1.1. α-Tomlinson Method

The α-Tomlinson method (Tomlinson, 1979/1995), based on total stress analysis, is used to relate the adhesion between the pile and clay to the undrained shear strength of the clay, Su and has been widely used especially in stiff clays. This method accounts for different pile materials (i.e., concrete, timber, or steel piles) and provides reasonable capacity estimates for large displacement piles. The method relies on the α-values, which in turn depend on the bearing embedment in stiff clay and the width of the pile. The ultimate unit side resistance may be taken as:

$$q_s = \alpha S_u \tag{3.2}$$

where:

α = adhesion factor (Fig 3.1), which depends on the bearing embedment in stiff clay and the width of the pile.

S_u = average undrained shear strength of the soil in the segment of interest.

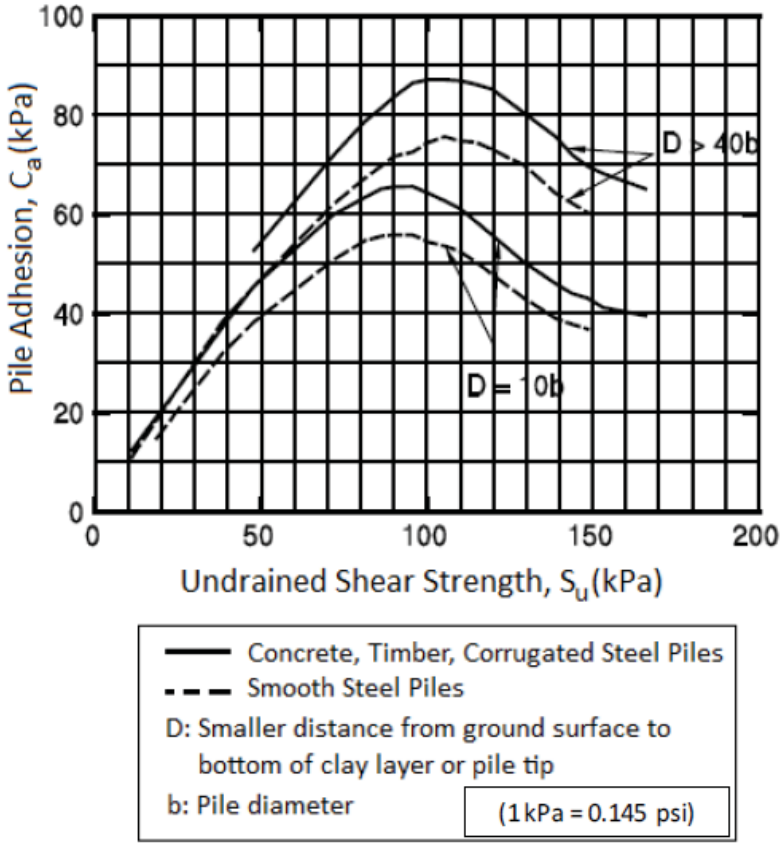


Figure 3.1a Adhesion values for piles in cohesive soils (after Tomlinson, 1979)

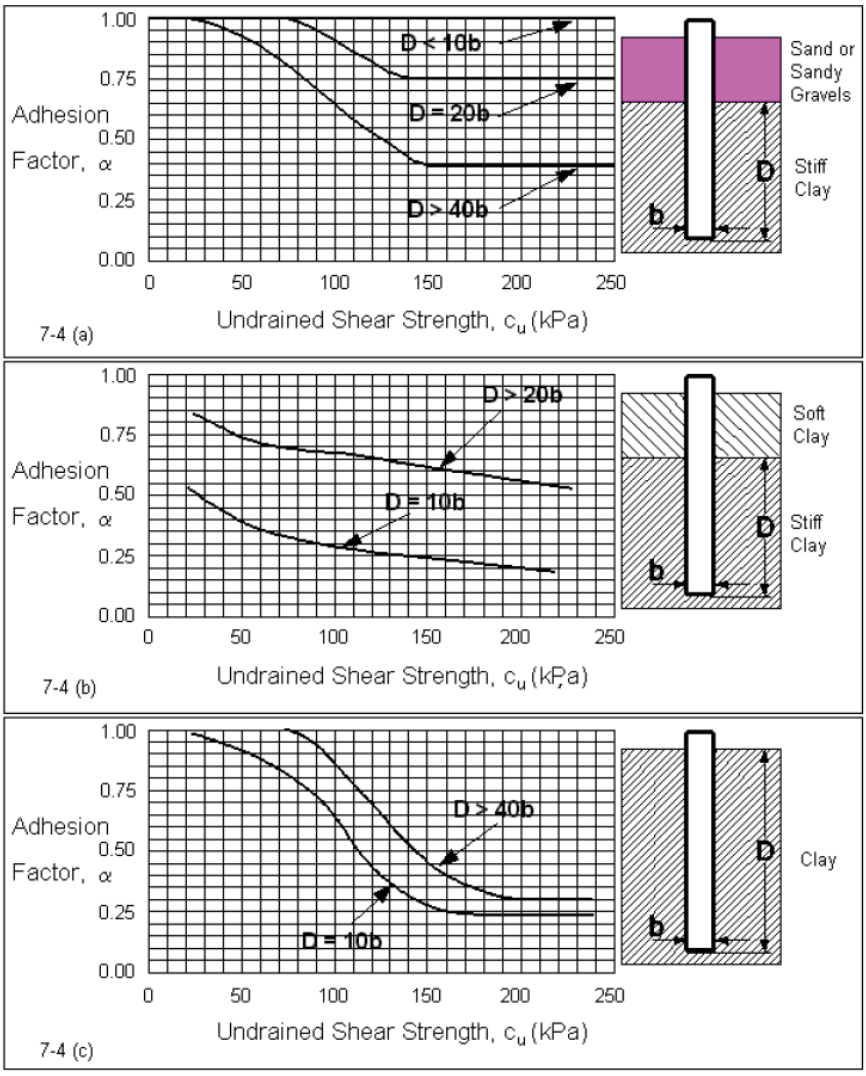


Figure 3.1b α factors; Tomlinson method (Tomlinson, 1995)

3.1.1.2. α-API Revised Method (1987)

The α-method (API-1974) is a semi-empirical, total stress approach for calculating the pile skin friction using the soil undrained shear strength (Su). This method was mainly developed for cohesive or clayey soils. It has been used for many years and has proven to provide reasonable design capacities for displacement and

non-displacement piles. The α-API method is similar to the α-Tomlinson method, and the ultimate unit side resistance, in the same unit as Su, is taken as:

$$q_s = \alpha S_u \qquad (3.3)$$

where: $\alpha = 0.5\ \psi^{-0.5}$ if $\psi \leq 1.0$

$\alpha = 0.5\ \psi^{-0.25}$ if $\psi > 1.0$, and max $\alpha = 1.0$

$\psi = S_u / \sigma_v'$, and

σ_v' = the vertical effective overburden pressure at the depth of interest.

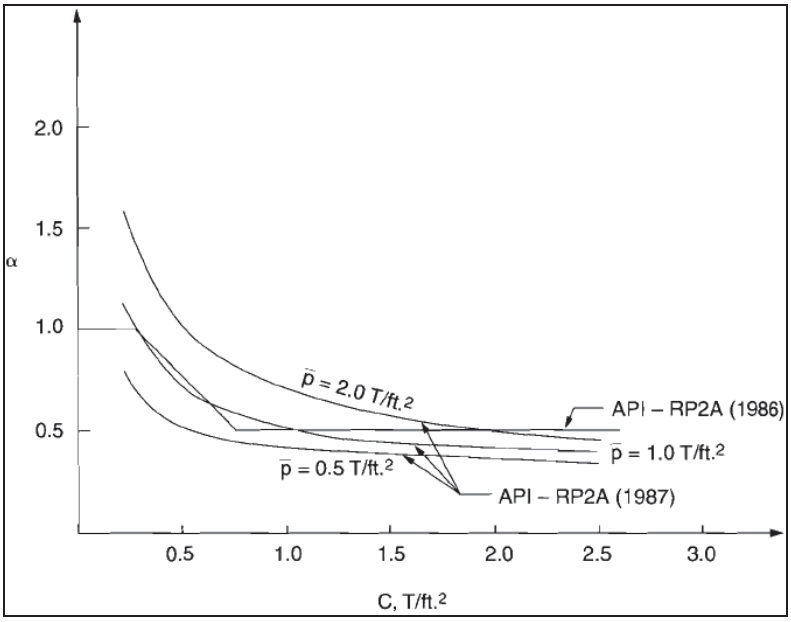


Figure 3.2 Comparison between α-factors calculated form API 1986 and 1987 (Reese, 2006)

The α-API method is a mixed method between total stress analysis (S_u) and effective stress analysis (σ_v'). It is much easier to use than the Tomlinson method. The α-API method has simple equations and no issue with considering other layers that lie above the bearing layer a thus it is easy to be automated.

3.1.1.3. β-Burland Method (1973)

The β-method (Burland, 1973) is a semi-empirical approach based on effective stresses calculated from the vertical effective overburden stress. The method was

developed to model the long-term drained shear strength. It can be used for different soil types such as clay, silt, sand, or gravel, and can even be used for layered soil profiles. According to Fellenius (1991), the beta factor (β) is affected by the soil type, mineralogy, density, strength, pile insulation technique, and other factors. The values of β range between 0.23 and 0.8, but cannot exceed 2 for over-consolidated soils as suggested by Esrig and Kirby (1979). The β-method has been found to work best for piles in normally consolidated and lightly over-consolidated soils. However, the method tends to overestimate the pile capacity for heavily over-consolidated soils (AASHTO-interim 2006). This method, suggested by Burland (1973), makes the following assumptions:

- Soil remolding adjacent to the pile during driving reduces the effective stress cohesion intercept on a Morhr's circle to zero

- The effective stress acting on the pile surface after dissipation of excess pore pressures generated by volume displacement is at least equal to the horizontal effective stress (K_0) prior to the pile installation

- The major shear distortion during pile loading is confined to relatively thin zone around the pile shaft, and drainage of this thin zone either occurs rapidly loading or has already occurred in the delay between the driving and loading.

With these assumptions Burland (1973) develop the simple equation:

$$q_s = K (\tan \delta) \sigma_v' \qquad (3.4)$$

where: K = horizontal stress ratio

δ = adhesion angle between soil and piles

σ_v' = vertical effective stress

Taking $\beta = K (\tan\delta)$, the equation can be rewritten as:

$$q_s = \beta\sigma_v' \qquad (3.5)$$

where: β = factor depended on the over-consolidation ratio OCR.

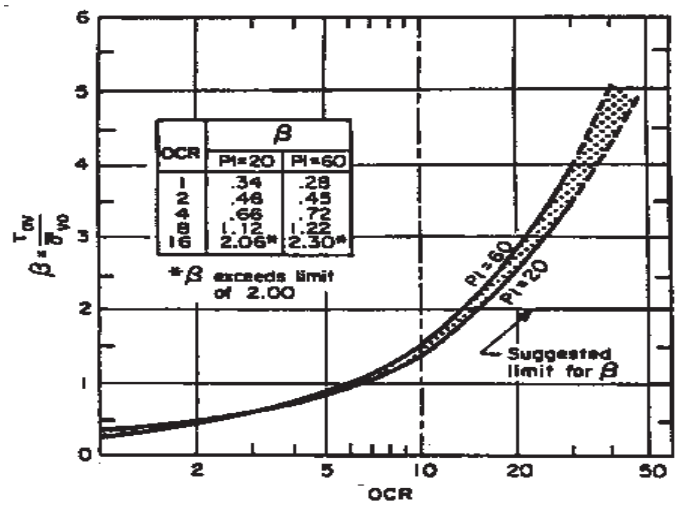


Figure 3.3 β factors (AASHTO 2007)

3.1.1.4. λ-Method

The λ method, proposed by Vijayvergiya and Focht (1972), is an empirical approach based on the assumption that the displacement of soil caused by pile driving results in a passive lateral pressure at any depth and that the unit skin resistance is:

$$q_s = \lambda(\sigma' + 2S_u) \quad (3.6)$$

Where:

σ'+2Su = Passive lateral earth pressure

σ' = Effective vertical stress at midpoint of soil layer under consideration

Su = Undrained shear strength of soil

λ = an empirical coefficient, which can be obtained form Figure 3.4, is pile length-dependent and applies over the total pile embedment depth. The value of λ was empirically determined by examining the results attained from various load tests that were conducted on steel pipe piles in cohesive soils, and thus, this method is more accurate if used for same soil and pile conditions.

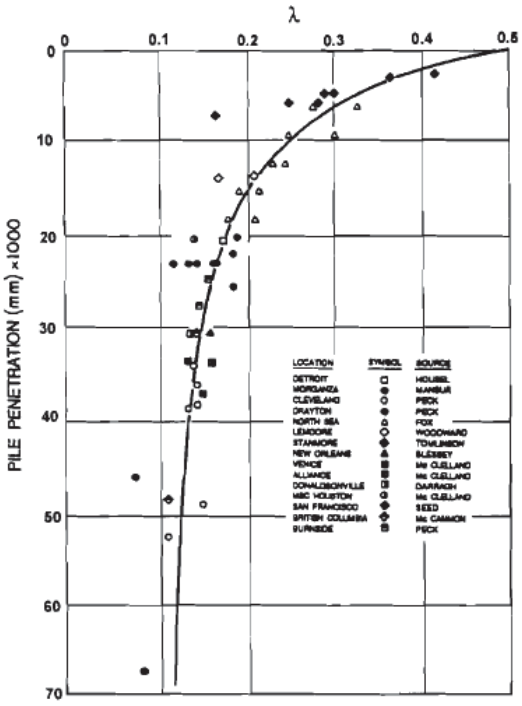


Figure 3.4 Coefficient for driven pile piles after Vijayvergiya and Focht (1972)

3.1.2. Tip Resistance in Cohesive Soil

O'Neill and Reese (1999) have developed a bearing capacity factor (Nc) to calculate the end bearing resistance of deep foundations in cohesive soil based on the soil undrained shear strength as follows:

$$q_p = N_c S_u \tag{3.7}$$

where:

q_p = Net unit end bearing resistance

Su = average undrained shear strength in the range from 2B to 3.5B below the tip, and B is the diameter of the pile.

B = Pile diameter

3.1.3 Side Resistance in Cohesionless Soil

In cohesionless soil, the side resistance of a pile is usually predicted using the adhesion angle, δ, or the relative density, D_r. The adhesion angle, δ, is related to the internal friction angle of the soil, φ, through the volume displacement, the material, the shape of the pile and the roughness of the pile. This section reviews different methods predicting the side resistance in cohesionless soil.

3.1.3.1 β-Bushan Method (1982)

Bushan (1982) suggests the unit side resistance for the large-displacement piles (close end piles, concrete piles) is related to effective stress as:

$$q_s = \beta\sigma v' \tag{3.8}$$

where: $\beta = 0.18 + 0.65\ Dr$, and

Dr = Relative density in decimals

3.1.3.2 Nordlund Method

The Nordlund method (Nordlund and Thurman, 1963) is a semi-empirical approach based on field observations from pile static load tests. It accounts for different pile shapes (i.e., constant diameter or tapered piles), as well as pile materials and types, including steel H-piles, closed and open-ended pipe piles, and timber piles, Monotubes and Raymond step taper piles. According to Hannigan et al. (2005), this method is preferred in cohesionless soils, such as sandy and gravelly soils, as the pile load tests used to develop the Nordlunds' design curves were conducted in sandy soils. Moreover, the load tests were conducted for piles with diameters (widths) less than 500mm (19.6 inches), which meant that the method over predicted the capacity for piles with widths larger than 500mm (19.6 inches).

Nordlund Method equation for computing the ultimate capacity of pile is as follow:

$$q_s = K_\delta C_F \sigma_v' \frac{\sin(\delta + \varpi)}{\cos\varpi} \tag{3.9}$$

where: K_δ = coefficient of lateral earth pressure at the depth of interest.

δ = friction angle between pile and soil. For non-taper piles:$\delta \leq \varphi$.

C_F = correction factor for K_δ when $\delta \neq \varphi$. $C_F \approx 0.6$ to 1.0.

σ_v' = effective over-burden pressure at the center of the layer of interest, and

ω = angle of the pile taper from vertical.

For a uniform cross section pile ($\omega = 0$), the Nordlund equation becomes

$$q_s = K_\delta C_F \sigma_v' \sin\delta \tag{3.10}$$

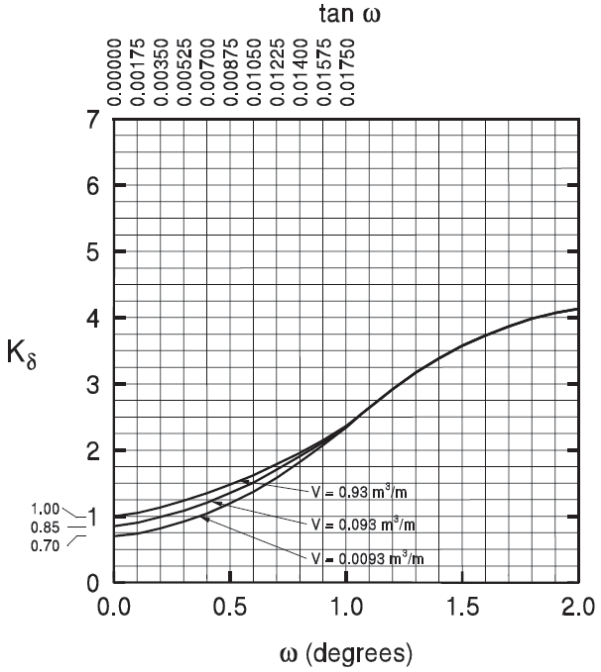


Figure 3.5 Design curve for evaluating K_δ when $\phi = 25$(after Nordlund, 1979)

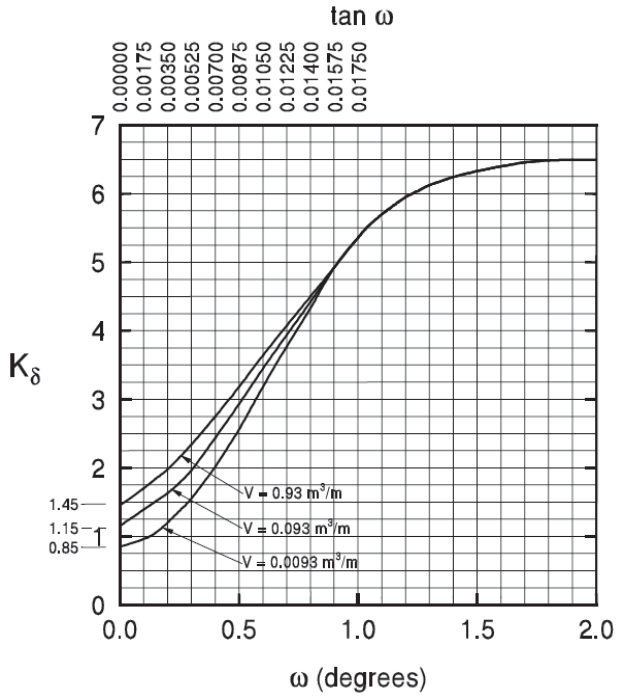


Figure 3.6 Design curve for evaluating K_δ when $\phi = 30$ (after Nordlund, 1979)

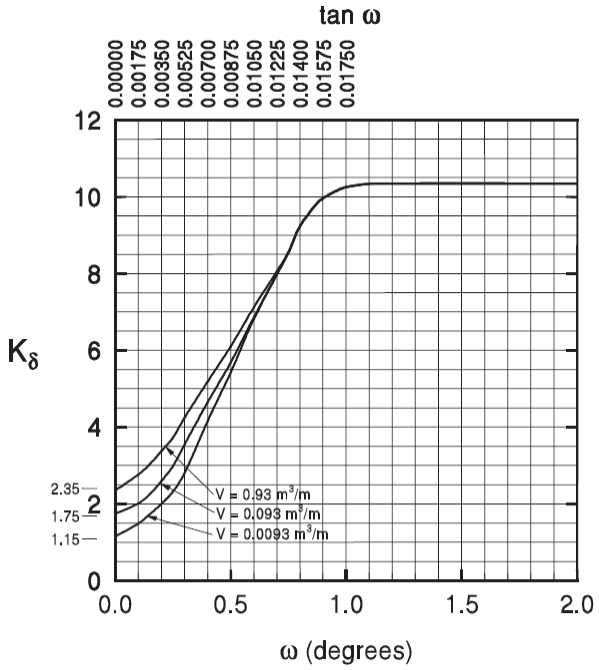


Figure 3.7 Design curve for evaluating K_δ when $\phi = 35$(after Nordlund, 1979)

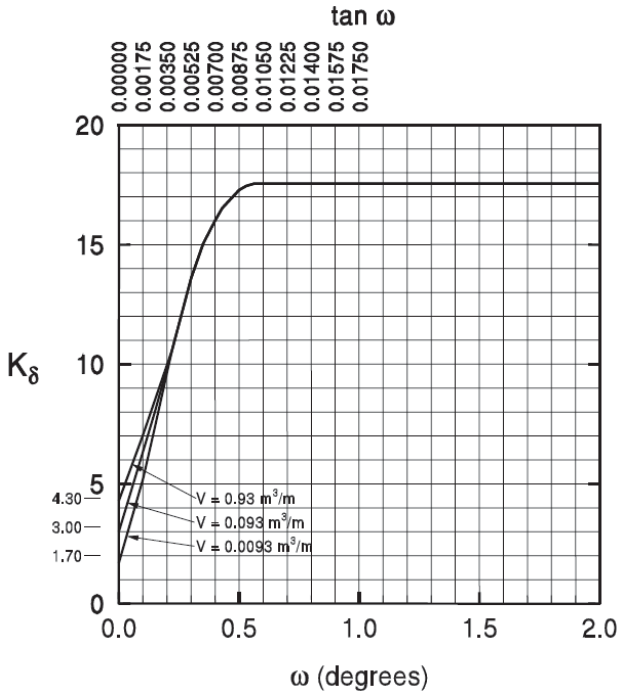
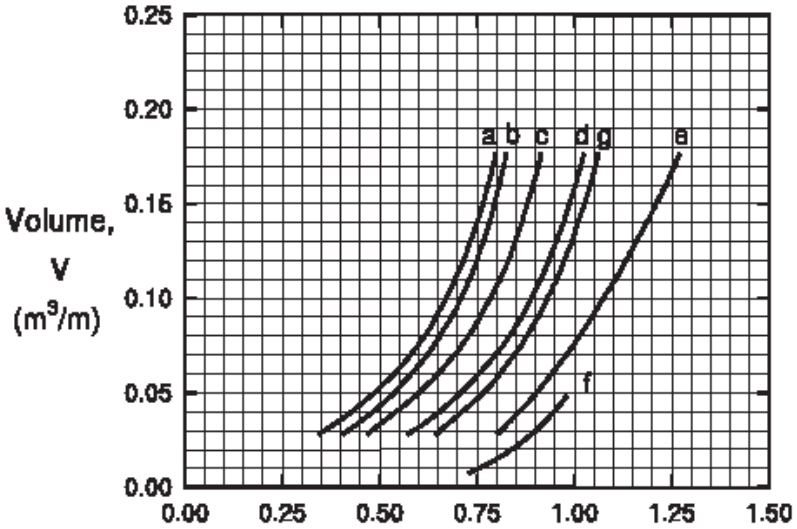


Figure3.8 Design curve for evaluating K_δ when $\phi = 40$ (after Nordlund, 1979)

δ/ φ



a. Pipe piles
b. Timber piles
c. Concrete piles
d. Raymond step taper piles
e. Raymond uniform taper piles
f. H piles
g. Tapered portion of monotube piles

Figure 3.9 Relation δ/ϕ and pile displacement (after Nordlund, 1979)

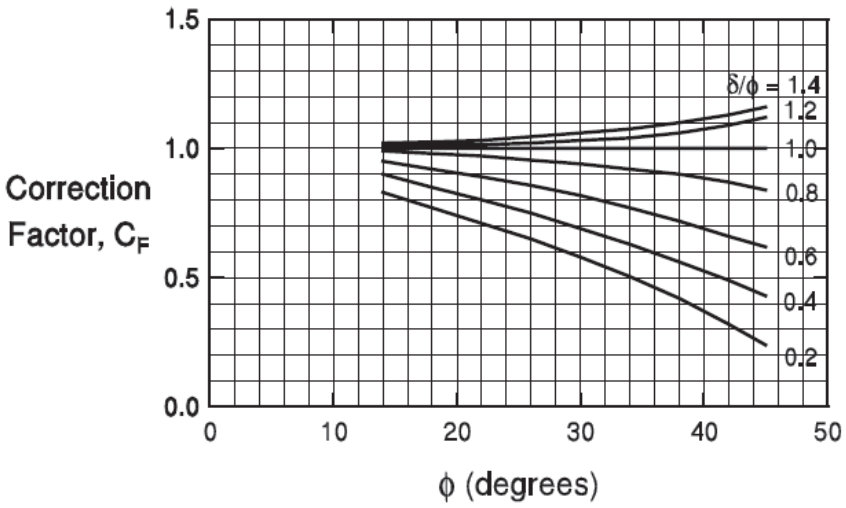


Figure3.10 Correction factor (C_F) for K_δ (after Nordlund, 1979)

3.1.4. Tip Resistance in Cohesionless Soil--Thurman Method

From bearing capacity theory, Thurman related the unit tip resistance in sand with effective stress as:

$$q_p = \alpha_t N'_q \sigma_v' \qquad (3.12)$$

where: α_t = dimensionless factor

N'_q =bearing capacity factor

σ_v' = effective overburden pressure at the pile tip. σ_v' is limited to 150 kPa (tip resistance reaches a limiting value at some distance below the ground),

q_p also has a limit as shown in

N'_q is very high at high internal friction angles (N'_q>250 when φ>42°). Therefore, some software, e.g. DRIVEN (FHWA, 1998) recommends the limit of only 36° for φ.

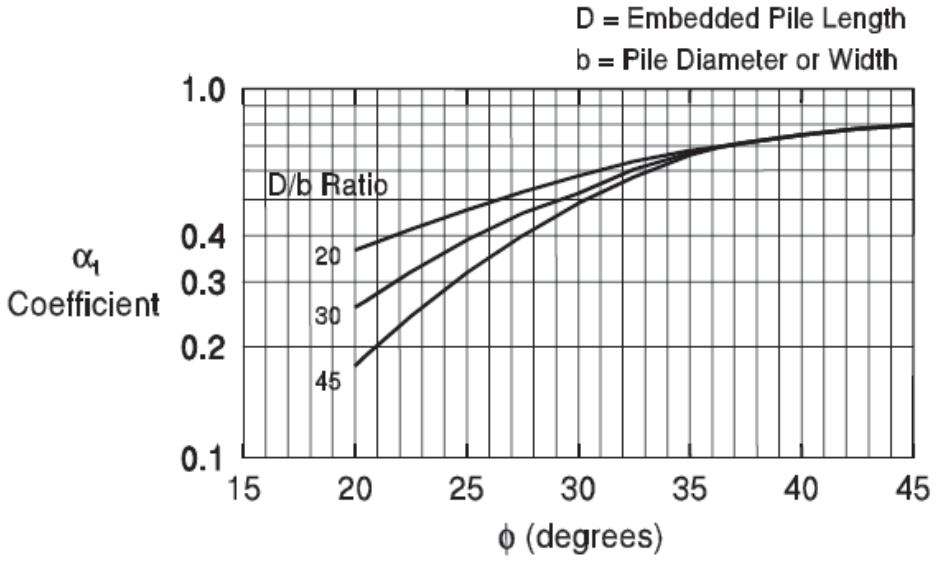


Figure 3.11 α_T coefficient (FHWA--DRIVEN, 1998)

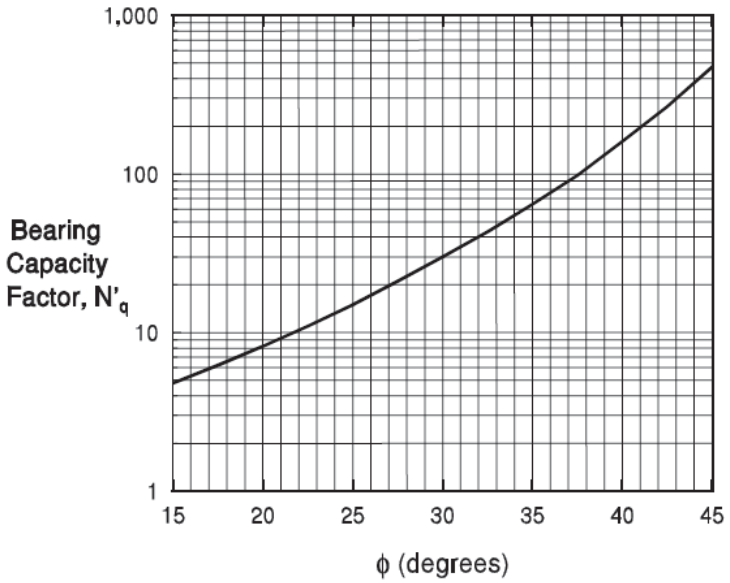


Figure 3.12 Bearing capacity factor Nq'(FHWA--DRIVEN, 1998)

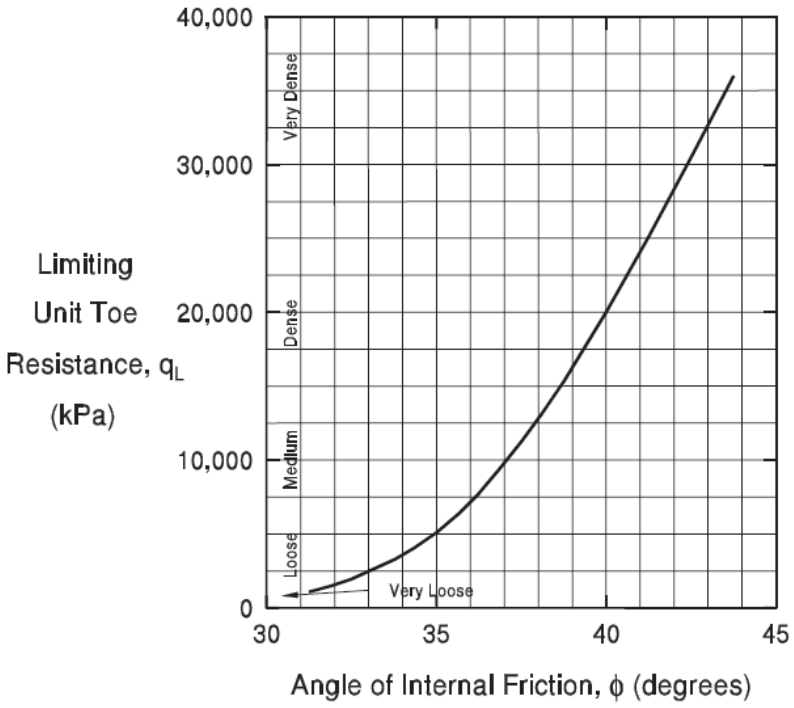


Figure 3.13 Relationship between Maximum Unit Pile Toe Resistance q_L (kPa) and Friction Angle for Cohesionless Soils (Meyerhof, 1976/1981).

3.1.5. Empirical Methods

3.1.5.1 Meyerhof Method for Piles in Cohesionless Soil

The SPT-Meyerhof method (Meyerhof, 1976/1981) is an empirical approach for calculating the pile capacity based on SPT tests conducted in cohesionless soils such as sands and non-plastic silts. According to the FHWA-LRFD reference manual (2007), the SPT method should be only used for preliminary estimates of the pile capacity, not for final design recommendations. This is due to the non-reproducibility of SPT N-values and simplified assumptions contained in the method. Meyerhof (1976) reported different correlations and provided some limitations on shaft and tip resistance according to the pile type (displacement or non-displacement pile).

- Meyerhof original paper (Meyerhof, 1976/1981)

$$q_s = k\, N_{60}\ (\text{kPa}) \leq 100\ \text{kPa} \qquad (3.13)$$

$$q_p = 0.4\ N_{60}t\ D/B \text{ (bar)} \quad (3.14)$$

$q_p \leq 4\ N_{60t}$ in sand and $q_p \leq 3\ N_{60t}$ in silt.

- ASHTO provision (AASHTO 1996/2007)

$$q_s = k_1\ N_{60} \text{ (kPa)} \leq 100 \text{ kPa} \quad (3.15)$$

$$q_p = 0.38\ N_{60t}'\ D/B \text{ (bar)} \quad (3.16)$$

$q_p \leq 4\ N_{60t}'$ in sand and $q_p \leq 3\ N_{60}t'$ in silt.

- Bowles (Bowles, 1996)

$$q_s = kN'_{60} \text{ (kPa)} \leq 100 \text{ kPa} \quad (3.17)$$

$$qp = 0.4\ N_{60(8+3B)}'\ D/B\ \leq 3.8\ N_{60(8+3B)}' \text{ (bar).} \quad (3.18)$$

- U.S. Army CORPS of Engineers, 1992:

$$qp = 0.38\ N_{60(8+3B)}\ D/B \leq 3.8\ N_{60(8+3B)} \quad (3.19)$$

where: k = 2 or 1.9 if use AASHTO for concrete piles and close end pipe piles

k = 1 or 0.96 if use AASHTO for H piles, open end pipe piles

N_{60} = uncorrected blow count and N'_{60} = corrected blow count

N_{60t} = uncorrected blow count near the pile tip

N_{60t}' = corrected blow count near the pile tip

$N_{60(8+3B)}$ = uncorrected N in the depth of 8B above tip and 3B below tip

$N_{60(8+3B)}'$ = corrected N in the depth of 8B above tip and 3B below tip

D = the embedment of the pile in cohesionless soil

B = the diameter or width of the pile cross-section

3.1.5.2 Schmertmann Method for SPT

The SPT-Schmertmann method (Lai and Graham, 1995) is an empirical approach based on SPT N-values, which is applicable in sand, clay, and mixed soils. This method is conservative, as it ignores the shaft resistance when the N-value is less than 5 blows/ft, and also limits the N-value to 60 blows/ft. The correlations used for calculating the skin friction for different piles and soil types are presented in Table 3.1. It is clear from Table 3.1 that all the correlations depend on the uncorrected SPT

N-values. The procedure of the Schmertmann method for SPT described below. First of all, the SPT blow count N is adjusted as shown below:

If $N < 5$ then $N = 0$ (ignores side resistance in weak soil)

If $N \geq 60$ then $N = 60$ (limit on side resistance)

Table 3.1 Side resistance-Schmertmann method for SPT

Ty-pe	Description	Ultimate unit side resistance q_s(KPa)		
		Concrete	Steel H piles	pipe piles
1	Plastic clay	0.0478N(110-N)	0.0359N(110-N)	18.58+20.93lnN
2	Clay-silt-sand mixtures Very silty sand, silts	0.0418N(110-N)	$-2.174+3.16N- 0.044N^2 +2.36x10^{-4} N^3$	23.27+14.08lnN
3	Clean sands	1.82N	1.11N	5.55+14.56lnN
4	Soft limestone, very shelly sand	0.96N	0.73N	1.72+12.83lnN

At any point A, the unit tip resistance is

$$q_{p@A} = \frac{\text{weighted average of } q_p \text{ 8B above A} + \text{weighted average of } q_p \text{ 3.5B below A}}{2}$$

The weighted average of q_p is based on values calculated from Table (3.2)

Table 3.2 Tip resistance-Schmertmann method for SPT

Type	Description	Ultimate unit end bearing q_p (KPa)	
		Concrete and H piles	Pipe piles
1	Plastic clay	67 N	0.46 N
2	Clay-silt-sand mixtures Very silty sand, silts	153 N	92 N
3	Clean sands	306 N	126 N
4	Soft limestone, very shelly sand	345 N	184 N

For concrete and H piles, the mobilized tip resistance is expected to be one third (1/3) of the ultimate tip resistance. For pipe piles, the mobilized tip resistance is expected

to be one half (1/2) of the ultimate tip resistance. The ultimate resistance is only fully mobilized when the bearing embedment is sufficient, i.e. $D_A = D_C$

where: D_a = actual bearing embedment, and D_c = critical bearing embedment

Table 3.3 Critical depth ratio--Schmertmann method for SPT

Soil Type	Description	Critical depth ratio (D_C/B)
1	Plastic clay	2
2	Clay-silt-sand mixtures Very silty sand, silts	4
3	Clean sands N = 12 or less N = 30 or less N greater than 30	6 9 12
4	Soft limestone, very shelly sand	6

If $D_A < D_C$ and the bearing layer is stronger than the overlying layer, then:

$$q_p = q_{LC} + \frac{D_a}{D_c}(q_T - q_{LC}) \tag{3.20}$$

$$f_i = \frac{f_{io}}{q_T}\left[q_{LC} + \frac{D_a}{2D_c}(q_T - q_{LC})\right] \tag{3.21}$$

If $D_A > D_C$ and the bearing layer is stronger than the overlying layer, then:

$$f_{iLC-D} = \frac{f_{ioLC-D}}{q_{CD}}\left[q_{LC} + 0.5(q_{CD} - q_{LC})\right] \tag{3.22}$$

where: q_p = Corrected tip resistance

q_{LC} = Unit tip resistance at layer change

q_T = Uncorrected unit tip resistance at pile tip

f_i = Corrected side resistance in the bearing layer

f_{io}= Uncorrected side resistance in the bearing layer

f_{iLC-D} = Corrected side resistance between the top of the bearing layer and the critical depth

f_{ioLC-D}= uncorrected side resistance in the bearing layer from the top of the bearing layer to the critical depth

q_{CD} = uncorrected unit tip resistance at D

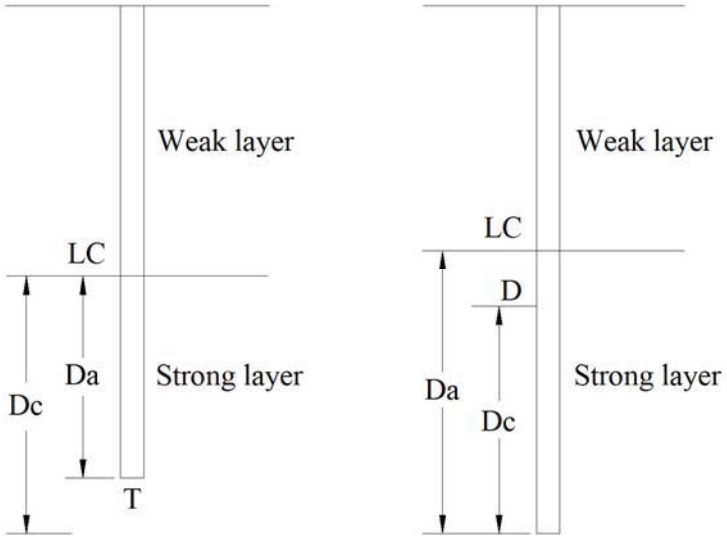


Figure 3.14 Corrected side and tip resistance

3.1.5.3 Nottingham and Schmertmann Method for CPT

Nottingham and Schmertmann (1975) developed an empirical approach for calculating the pile capacity based on the CPT, which is applied to cohesive and cohesionless soils. Correlations to CPT provide accurate pile design capacities, especially with driven piles. Moreover, it provides continuous readings for the soil profile and can take the effect of different soil layers into consideration. The cone penetration resistance, qc, is used to determine the tip resistance of piles and sleeve friction, f_s, is used to determine the skin friction resistance.

The ultimate tip resistance of piles may be taken as:

$$q_p = \frac{q_{c1} + q_{c2}}{2} \tag{3.23}$$

where:

- q_{c1} = the average q_c over a distance of yD below the tip (path a-b-c); sum q_c values in both the downward (path a-b) and upward (path b-c) directions; use actual q_c value along path a-b and the minimum path rule along path b-c; compute q_{c1} for y value from 0.7 to 4.0 and use the minimum q_{c1} value obtained

- q_{c2}= average q_c over distance of 8D above the pile tip (path c-e); use minimum path rule as for path b-c in q_{c1}, computation; ignore any minor "x" peak depression if in sand but include in minimum path if in clay

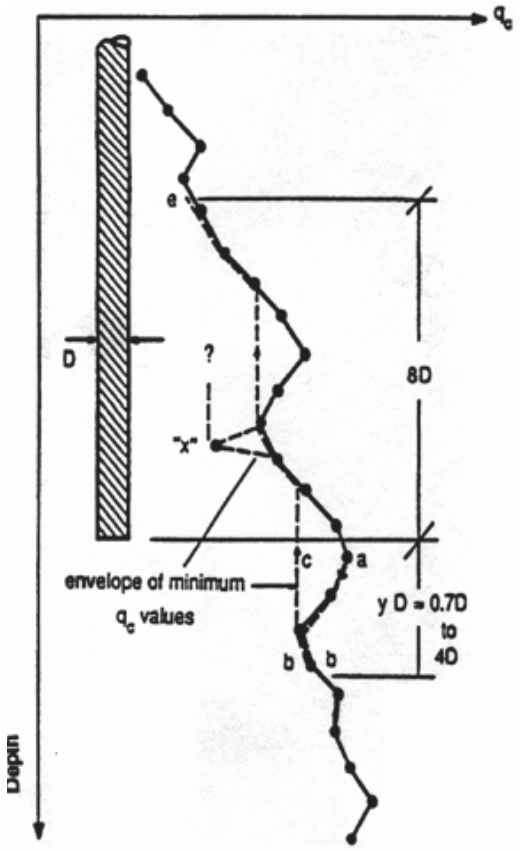


Figure 3.15 Tip resistance computation procedure--Nottingham 1975

Similarly, the nominal side resistance of piles may be taken as:

$$R_s = K_{s,c}\left[\sum_{i=1}^{N_1}\left(\frac{L_i}{8D_i}\right) f_{si} a_{si} h_i + \sum_{i=1}^{N_2} f_{si} a_{si} h_i + \right] \tag{3.24}$$

Where:

$K_{s,c}$= correction factor, K_c for clays, K_s for sands from figure (3.16a, 3.16b)

L_i=depth to middle of length interval at the point consider (mm)

D_i=pile width or diameter at the point considered (mm)

f_{si}= unit local sleeve friction resistance at the point considered (MPa)

a_{si}=pile perimeter at the point consider (mm)

h_i= length interval at the point considered (mm)

N_1= number of interval between the ground surface and a point 8D below the ground surface

N_2=number of interval between 8D below the ground surface and the tip of the pile

For a pile of constant cross-section (nontapered) equation (3.24) can be written as:

$$R_s = K_{s,c}\left[\frac{a_s}{8D}\sum_{i=1}^{N_1} L_i f_{si} h_i + a_s \sum_{i=1}^{N_2} f_{si} h_i\right] \qquad (3.25)$$

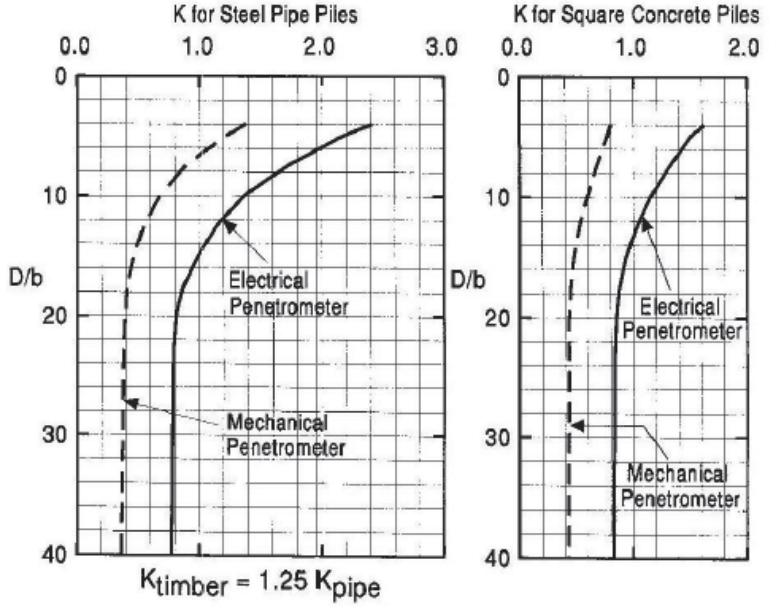


Figure 3.16a Ks ratio in cohesionless

Table 3.6: Represents CPT C_f values (after the FHWA, 2007)

Type of piles	C_f
Precast concrete	0.012
Timber	0.018
Steel displacement	0.012
Open end steel pipe	0.008

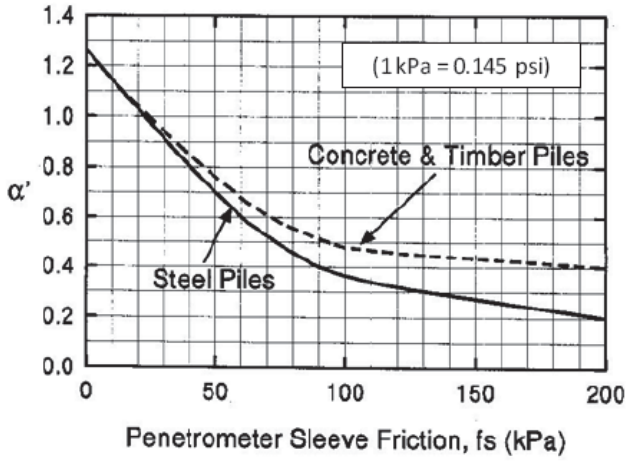


Figure 3.16b Kc ratio in cohesive soil

Table 3.5 Methods for calculating axial loading capacity of a driven pile

Soil Type	**Methods**	Side resistance	Tip resistance	Parameters required
Cohesive Soil	α-Tomlinson (Tomlinson,1980/1995)	$q_s = \alpha S_u$	$q_p = 9\ S_u$	S_u
	α-API (Reese et al., 1998)			S_u
	β in cohesive (AASHTO, 1996/2000)	$q_s = \beta\sigma'$		OCR
	λ (US Army Corps of Engineers, 1992)	$q_s = \lambda(\sigma'+2S_u)$		S_u
Cohesionless Soil	β in cohesionless (Bowles, 1996)	$\beta\sigma'$		D_r
	Nordlund and Thurman (Hannigan et al., 1995)	$q_s = K_\delta C_F \sigma' \frac{\sin(\delta+\varpi)}{\cos\varpi}$	$q_p = \alpha_t\ N'_q\ \sigma'$	φ
	Meyerhof SPT (Meyerhof, 1976/1981)	$q_s = k\ N$	$q_p = 0.4D/BN'$	SPT-N value
Cohesion/cohesionless Soil	Schmertmann SPT (Lai and Graham, 1995)	q_s = function(N)	q_p = fn(N)	SPT-N value
	Schmertmann CPT (McVay and Townsend, 1989)	q_s = function(f_s)	q_p = fn(q_c)	q_c, f_s

3.2 Axial Loading Capacity of a Drilled Shalf

The ultimate resistance of a pile, R_{ult} (or R_n--Norminal resistance), is given below:

$$R_{ult} = R_P + R_s \tag{3.26}$$

where: pile tip resistance $R_p = q_p A_p$,

pile side resistance $R_s = \sum q_{si} \Delta z_i$ a

q_p = unit tip resistance.

q_s = unit side resistance, which is regarded as constant along segment Δz_i of the pile.

a = perimeter of the pile's shaft, and

A_p = area of the tip of the pile.

3.2.1 Side Resistance in Cohesive Soils

3.2.1.1 FHWA method

The following equation gives the α method for the evaluation of the skin (side or frictional) resistance of drilled shafts in cohesive soils at depth z:

$$q_s = \alpha s_u \tag{3.27}$$

where

q_s = ultimate skin resistance at depth z

S_u = undrained shear strength (cohesion) at depth z

α = empirical adhesion factor depends on undrained cohesion.

The values of α varies from 0.3 to 1.0 and the following best-fit functional relationship (Eq. 3.28) shows that the α values decrease with the increasing undrained shear strength (Kulhawy and Jackson (1989):

$$\alpha = 0.21 + 0.25 \frac{p_a}{S_u} \tag{3.28}$$

where p_a = atmospheric pressure. In other words, the soft normally consolidated clay has a higher α value than the hard overconsolidated clay.

O'Neill and Reese (1999) recommended the following equation for the average value of α :

$$\alpha = 0.55 \text{ for } \frac{S_u}{p_a} \leq 1.5 \tag{3.29}$$

and

$$\alpha = 0.55 - 0.1\left(\frac{S_u}{p_a} - 1.5\right) \text{ for } 1.5 \leq \frac{S_u}{p_a} \leq 2.5 \tag{3.30}$$

For the case of $S_u / p_a > 2.5$, skin resistance should be calculated as the methods for cohesive intermediate geomaterials (O'Neill and Reese, 1999)

The total skin resistance, Q_s, is equal to the peripheral area of the shaft multiplied by the unit side resistance shown as follows:

$$Q_s = \pi D \sum \alpha^i S_u^i L^i \tag{3.31}$$

where

D = pile diameter

L^i = thickness of layer i, where the values of α and S_u are constants.

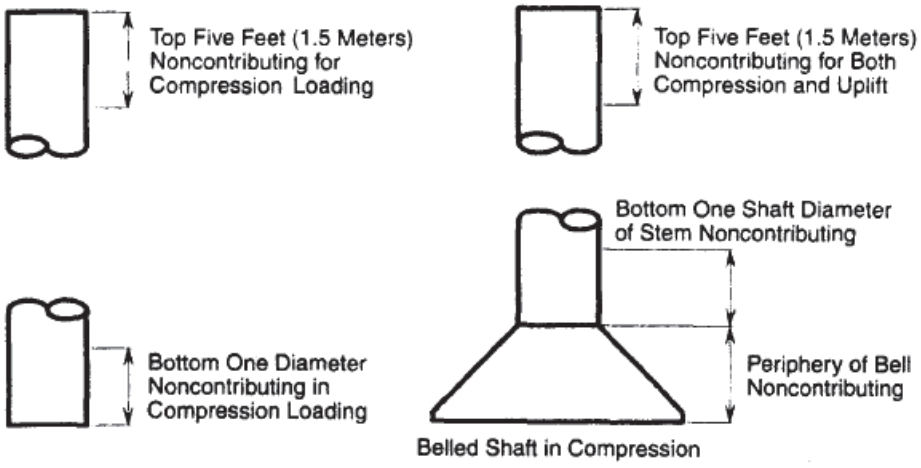

Top Five Feet (1.5 Meters) Noncontributing for Compression Loading
Top Five Feet (1.5 Meters) Noncontributing for Both Compression and Uplift
Bottom One Shaft Diameter of Stem Noncontributing
Periphery of Bell Noncontributing
Bottom One Diameter Noncontributing in Compression Loading
Belled Shaft in Compression

Figure3.17 Explanation of Portions of Drilled Shaft Not Considered in Computing Side Resistance in Clay (O'Neilll and Reese, 1999)

The peripheral areas over which side resistance in clay is computed are show in Figure 3.17. The upper portion of the shaft is excluded for compression to account for soil shrinkage in the zone of seasonal moisture change. The lower portion of shaft is exclusion when the shaft is loaded is compression because downward movement of the base will generate tensile stress in soil that will be relieved by cracking of soil and porewater suction will be relieved by inward movement of ground water.

3.2.2 End Bearing in Cohesive Soils

3.2.2.1 FHWA method

The prediction of end bearing capacity of drilled shaft in clays is much less uncertain than is the prediction of skin resistance (Reese et al. 2006). The equation below is used for calculating the net base resistance:

$$Q_p = A_p S_u N_c^* \tag{3.32}$$

where A_p = area of the base; S_u = an average undrained shear strength of the clay calculated over a depth of two time of diameter below the base (Reese et al., 2006); N_c^* = bearing capacity factor usually taken to be 9 when the ratio L/D_b is 4 or more (Das, 1999). According to O'Neill and Reese (1999), for the straight shaft, the full value of $N_c^* = 9$ is obtained when the base movement of about 20% of D. If the base movement is unknown, the bearing capacity factor N_c^* can be calculated by (Reese et al., 2006):

$$N_c^* = 1.33\left(\ln I_r + 1\right) \tag{3.33}$$

where I_r is the rigidity index of saturated clay under undrained condition:

$$I_r = \frac{E_s}{3S_u} \tag{3.34}$$

where E_s is undrained Young's modulus. If E_s is not measured, N_c^* and I_r can be estimated from:

Table 3.6 Values of I_r and N_c^* (Reese, et al, 2006)

S_u	$E_s/3S_u$	N_c^*
24 kPa (500 lb/ft^2)	50	6.5
48 kPa (1000 lb/ft^2)	150	8.0
≥ 96 (2000 lb/ft^2)	250-300	9.0

3.2.3 Side Resistance in Cohesionless Soil

3.2.3.1 FHWA method

The following equation is used to calculate the ultimate unit skin resistance in sand at depth z:

$$q_s = K\sigma_z' \tan\delta \tag{3.35}$$

Where:

- K = a parameter that includes the effect of the lateral pressure coefficient and a correlation factor - σ_z' = vertical effective stress in soil at depth z

- δ = friction angle at the interface of pile surface and soil.

The total side resistance calculated from the summation of each layer of unit side resistance multiplied by perimeter and layer thickness is shown as follow:

$$Q_s = \pi D \sum K^i \sigma_z'^i \tan\varphi_c^i L_i \tag{3.36}$$

O'Neill and Reese (1999) suggested the expression for the ultimate unit skin resistance in sand:

$$q_s = \beta\sigma_z' \leq 200 \text{ kPa} \tag{3.37}$$

and

$$Q_s = \pi D \sum \beta^i \sigma_z'^i L_i \tag{3.38}$$

Where: In sands

$\beta = 1.5 - 0.135z(ft)^{0.5}$, ($0.25 \leq \beta \leq 1.20$) for SPT $N_{60} \geq 15$ (blows/ft)

$$\beta = \left(N_{60}/15\right)\left(1.5 - 0.135z(ft)^{0.5}\right) \text{ for SPT } N_{60} < 15 \text{ (blows/ft)}$$

In gravelly sands or gravels when, use the method for sands if $N_{60} < 15$ (blows/ft) (O'Neill and Reese, 1999)

Table 3.7 β for Gravelly sands and Gravels (Rollins et al., 2005)

Percentage Gravel	β
Smaller than 25%	$\beta = 1.5 - 0.135z^{0.5};\ 0.25 \le \beta \le 1.20$
Between 25% and 50%	$\beta = 2.0 - 0.0615z^{0.75};\ 0.25 \le \beta \le 1.80$
Greater than 50%	$\beta = 3.4e^{-0.0265z};\ 0.25 \le \beta \le 3.0$

3.2.3.2 Reese and Wright method

Reese and Wright (1977) proposed a semi-empirical method to estimate the unit skin friction (qs) and unit bearing (q_p) for drilled shafts founded in sands using uncorrected SPT blow count, N

Unit skin friction for, q_s, for sands:

For N<53 $q_s = 0.0028N$ (Mpa)

For 53<N<100 $q_s = 0.00021(N-53) + 0.15$(Mpa)

In the case of multiple soil layer, i.e. sand and clay, the FHWA approach for clay

3.2.4 End Bearing in Cohesionless Soil

3.2.4.1 FHWA method

According to O'Neill and Reese (1999), tip resistance for cohesionless soil with blow count $N_{SPT} \le 50$ (blows/ft) can be found by following equation:

$$q_p = 57.5N_{SPT} \text{ kPa} \le 2.9 \text{ MPa} \qquad (3.39)$$

When $N_{SPT} > 50$ (blows/ft), q_p should be calculated according to equations for intermediate geometerials (IMGs) as:

$$q_p = 0.59\left[N_{60}\left(\frac{p_a}{\sigma'_v}\right)\right]\sigma'_v \qquad (3.40)$$

Where: p_a = atmospheric pressure

σ'_v = vertical effective stress at the tip elevation of the shaft (MPa)

N_{60} =should be limited to 100 in Eq if higher values are measured

3.2.4.2 Reese and Wright method

Unit end bearing, q_p for sands:

For N < 60 $q_p = 0.064*N$ (Mpa)

For N > 60 $q_p = 3.8$ (Mpa)

N: is the uncorrected N_{spt} value

3.2.5 Side Resistance in Rock

Drilled shaft in rock subject to compressive loading shall be designed to support factored load in:Side-wall shear comprising skin friction on the wall of the rock socket; or End bearing on the material below the tip of the drilled shaft or a combination of both. For the drilled shafts socket in to rock, shaft resistance, In MPa, may be taken as (Horvath and Kenney 1979)

$$q_s = 0.65\alpha_E p_a (q_u / p_a)^{0.5} < 7.8 p_a (f'_c / p_a)^{0.5} \qquad (3.41)$$

Where:

q_s = uniaxial compressive rock (MPa)

p_a= atmospheric pressure

α_E = reduction factor to account for jointing in rock as provide in table (3.6)

f'c= concrete compressive strength (MPa)

Table 3.8 Estimation of α_E (O'Neil and Reesse, 1999)

Em/Ei [(a)]	α_E
1.0	1.0
0.5	0.8

0.3	0.7
0.1	0.55
0.05	0.45

(a) E_m: rock mass modulus E_i: intact rock modulus

3.2.6 Tip Resistance in Rock

End bearing for drilled shafts in rock may be taken as follows:

- If the rock below the base of the drilled shaft to depth of 2.0B is either intact or tightly joints, i.e., no compressible or gouge filled seams and the depth of the socket is greater than 1.5 B

$$q_p = 2.5 q_u \tag{3.42}$$

- If rock below the base of the shaft to a depth of 2.0B is joints have random orientation and the condition of joints can be evaluated as:

$$q_p = \left[\sqrt{s} + \sqrt{(m\sqrt{s} + s} \right] q_u \tag{3.43}$$

Where: s, m= fractured rock mass parameters and are specified in table ()

q_u= unconfined compressive strength of roc (MPa)

Table 3.9 Methods for calculating axial loading capacity of a drilled shaft

Soil Condition	Resistance Component	Equations	Parameters
Cohesive Soil	Skin Friction	FHWA method: $q_{sz} = \alpha s_{uz}$ $Q_s = \pi D \sum \alpha^i S_u^i L^i$	α: shear strength reduction factor Suzi: undrained shear strength at depth z qsz: ultimate load transfer in skin friction at z dA: differential area of the shaft L: penetration depth of the drilled shaft below ground surface
	End Bearing	FHW method $Q_p = A_p S_u N_c$	Nc: bearing capacity factor Su: average undrained shear strength of the clay between the base and a depth of 2B Ir: rigidity index of the soil Es: Young's modulus of the soil
Cohesionless Soil	Skin Friction	FHWA method: $q_s = \beta \sigma_z' \le 200$ kPa	σ' : vertical effective stress in soil at depth z z: depth below the ground surface

		$Q_s = \pi D \sum \beta^i \sigma_z'^i L_i$ $\beta = 1.5 - 0.135 z(ft)^{0.5}$, $(0.25 \le \beta \le 1.20)$ if $N_{60} \ge 15$ $\beta = (N_{60}/15)(1.5 - 0.135 z(ft)^{0.5})$ if $N_{60} < 15$ (blows/ft) Reese and Wright method: For N<53 qs = 0.0028N (Mpa) For 53<N<100 qs = 0.00021(N-53) + 0.15(Mpa)	
	End Bearing	FHWA method: $q_p = 57.5 N_{SPT}$ kPa ≤ 2.9 MPa when $N_{SPT} \le 50$ $q_p = 0.59 \left[N_{60} \left(\frac{p_a}{\sigma'_v} \right) \right] \sigma'_v$ when $N_{SPT} > 50$ Reese method: For N < 60 qp = 0.064*N (Mpa) For N > 60 qp = 3.8 (Mpa)	N_{SPT}: average blow count from the zone between the base and a depth of 2B
Rock	Skin Friction	$q_s = 0.65 \alpha_E p_a (q_u / p_a)^{0.5}$ $< 7.8 p_a (f'_c / p_a)^{0.5}$	qs = uniaxial compressive rock (MPa) pa= atmospheric pressure αE = reduction factor to account for jointing in rock as provide in table (3.6) f'c= concrete compressive strength (MPa)
	End Bearing	$q_p = 2.5 q_u$ $q_p = \left[\sqrt{s} + \sqrt{(m\sqrt{s} + s} \right] q_u$	

3.3 Piles Dynamic Analysis

3.3.1 The Case Method

Static pile bearing capacity can be calculated by Case method using following equation:

$$R_s = (1 - J_c)\frac{[F_{M1} + Z\dot{u}_{M1}]}{2} + (1 + J_c)\frac{[F_{M2} - Z\dot{u}_{M1}]}{2} \tag{3.44}$$

Where:

F_{M1} is measured force at time t_1

F_{M2} is measured force at time $t_1 + 2L/c$

$\dot{u}_{M1}$ is measured velocity at time t_1

$\dot{u}_{M2}$ is measured velocity at time $t_1 + 2L/c$

J_c is Case damping

Z: Impedance

The impedance, Z, of a pile is a function of the dynamic modulus, E, the wave speed, c, and the pile cross-sectional area, A.

$$Z = \frac{EA}{c} \tag{3.45}$$

The wave speed can be calculated by the following equation

$$c = \frac{2L}{t} \tag{3.46}$$

Where: L: Length of the Pile

t: Time Required for the Pulse to Travel Twice the Pile Length

The dynamic modulus of the pile material, E, is presented in the following equation

$$E = \rho c^2 \tag{3.47}$$

Where: ρ : mass density of the pile material

c: the wave speed.

Since the Case damping constant is assumed, the static capacity will be known from above equation.

3.3.2 The Energy Approach

The Energy Approach method or "Paikowsky" is a simplified energy approach formulation for the prediction of pile resistance based on the dynamic measurements recorded during driving. The basic assumption of the method is an elasto-plastic load displacement pile-soil reaction. The Paikowsky method uses as input parameters the maximum calculated transferred energy and maximum pile displacement from the measured data together with the field blow count. Equation () presents the solution for the dynamic pile capacity R_u (Paikowsky, 1994).

$$R_u = \frac{E_{\max}}{Set + \frac{(D_{\max} - Set)}{2}} \tag{3.48}$$

Where: R_u: maximum pile resistance

E_{max}: measured maximum energy delivered to the pile

$D_{m:ax}$: measured maximum pile top displacement

Set: permanent displacement of the pile at the end of the analyzed blow, or 1/measured blow count.

3.3.3 The Signal Matching

The Case Pile Wave Analysis Program (CAPWAP) is a computer program that combines the wave equation's pile and soil model with the Case method of forces and velocities from PDA. The CAPWAP solution includes the static total resistance, skin friction and toe bearing of the pile, in addition to the soil resistance distribution, damping factors, and soil stiffness. The program calculates acceleration, velocities, displacements, waves up, waves down and forces at all points along the pile. The procedure used by CAPWAP includes inputting the force trace obtained from PDA and adjust the soils parameters until the velocity trace obtained from PDA can be recreated. It should be noticed that the opposite procedure (i.e. input velocity trace and generate the force trace) can also be performed. When the match obtained is unsatisfactory, it is necessary to modify the soil parameters, until reaching a

satisfactory match results. The process of running CAPWAP is considered an iterative one.

3.4 Static Load Test

Static Load Tests (SLTs) accurately measure the actual pile behavior under axial vertical compressive loading and characterize the load-settlement relationship at the pile head. Load testing is the most definitive method for determining the nominal capacity of a pile. Testing a pile to failure provides valuable information to the design engineer and is recommended for design verification purposes. In difficult soil and bedrock conditions, the SLT results are the only means of identifying the actual pile capacity and also helps in generating databases to find the resistant factors.

3.4.1 ASTM Procedures

The American Standard for Testing and Materials (ASTM) have four static load test procedures including the standard loading procedure, cyclic loading, quick load test, and constant rate of penetration.

3.4.1.1 Standard Loading Procedure

The standard ASTM method calls for piles to be loaded to 200% of the anticipated design load, unless failure occurs first. The pile shall be loaded in increments of 25% of the total test load. Each load increment will be held until the rate of settlement is not greater than 0.25 mm/hr (0.01 inches per hour) but no longer than two hours per increment. In the event the pile has not failed, hold the total load on the test pile between 12 and 24 hours until the settlement is not greater than 0.25 mm/hr (0.01 inches per hour). After the settlement rates have been satisfied, remove the load in decrements of 25% of the total test load with one hour between decrements.

3.4.1.2 Cyclic Loading

The pile is loaded in a series of four cycles. The first cycle is loaded in increments of 25% of the total design load up to 50% and each load increment is held for one hour. At 50% the pile is unloaded in decrements of 25% until the entire load is removed from the pile with 20 minutes between decrements. Cycles two, three, and four are loaded to 100%, 150%, and 200%, respectively in increments of 50% of the total design load. Each load increment is held for one hour during each cycle. Once the maximum load is reached per cycle, the pile is unloaded to zero in decrements of 50% of the maximum applied load with 20 minutes between each unloading.

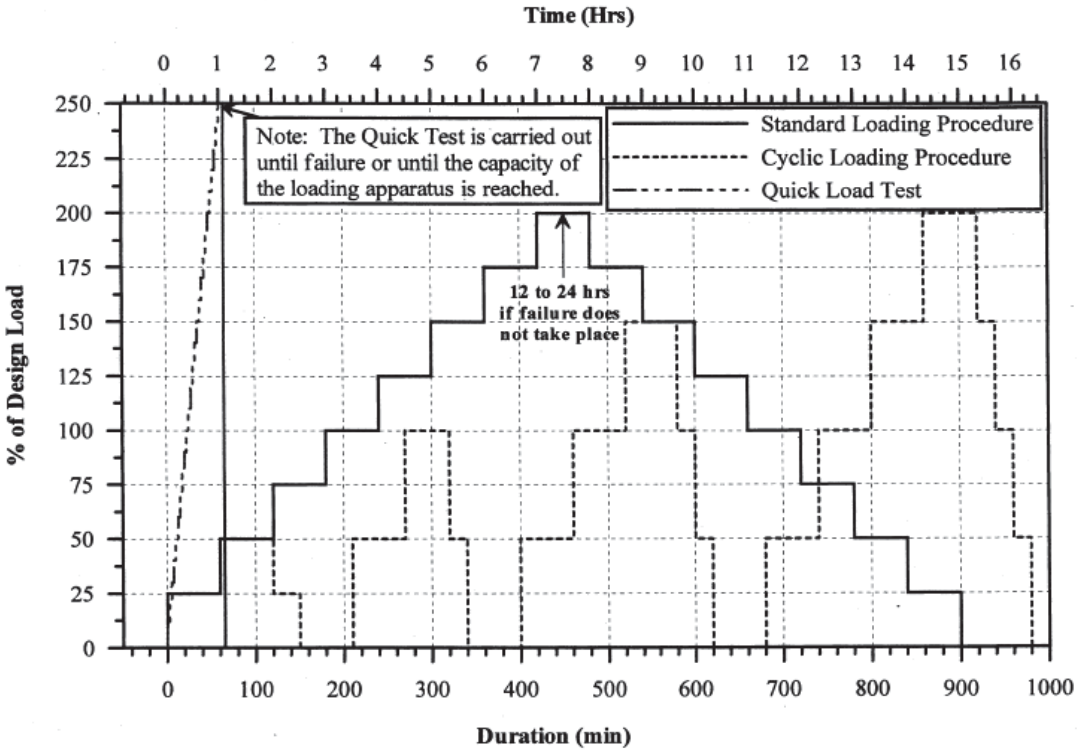

Time (Hrs)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
% of Design Load
250 225 200 175 150 125 100 75 50 25 0
Note: The Quick Test is carried out until failure or until the capacity of the loading apparatus is reached.
Standard Loading Procedure
Cyclic Loading Procedure
Quick Load Test
12 to 24 hrs if failure does not take place
0 100 200 300 400 500 600 700 800 900 1000
Duration (min)

Figure 3.18 Static pile load testing procedures according to ASTM (Paikowsky, 2004)

3.4.1.3 Quick Load Test Method for Individual Piles

The load is applied in increments of 10 to 15% of the design load with a constant time interval of 2.5 minutes between loading increments. Load increments are added until continuous jacking is required to hold the test load or until the

specified capacity of the loading device is reached. After one of these criteria is reached, the load is held for five minutes and the full load is removed from the pile.

3.4.1.4 Constant Rate of Penetration

The pile is loaded at a constant rate of penetration 0.3 to 1.3 mm/min (0.01 to 0.05 in/min) for cohesive soils or 0.8 to 2.5 mm/hr (0.03 to 0.1 in/min) for granular soils. The pile is continually loaded until no further increase in load is necessary for the constant rate of penetration of the pile under the predetermined rate or the capacity of the pile is reached. If the pile continues to settle under the constant load, the load is held until the pile has moved at least 15% of the pile diameter and then the pile is unloaded completely. If maximum capacity of the pile is reached before failure, the total load is released.

3.4.2 Vietnamese Procedures

Most of static load data from Vietnam use the same standard load procedure from ASTM and cyclic load procedure but in Vietnam the pile is loaded in a series of two cycles instead of four cycles in ASTM. The first cycle is loaded up to 100% of the anticipated design load in increments of 25% and each load increment is held for one hour. At 100% the pile is unloaded in decrements of 25% until the entire load is removed from the pile with 20 minutes between decrements. Cycles two is loaded to 200%, respectively in increments of 25% of the total design load. Each load increment is held for one hour during each cycle. Once the maximum load is reached per cycle, the pile is unloaded to zero in decrements of 50% of the maximum applied load with 20 minutes between each unloading.

3.5 Interpretation from Static Load Tests

3.5.1 Davisson's Method

The Davisson method (Davisson 1972) is one of the most popular methods and it is based on the elastic compression of the pile. This method takes into account the elastic shortening of pile under the axial load, the required relative movement 0.15 in

between the soil and the pile for full mobilization of side friction, and the amount of tip movement ($1/120^{th}$ of pile diameter in inches) for mobilization of tip resistance. The ultimate load of a pile can express in the following form:

$$w_{ult} = 0.004L_R + \frac{B}{120} + \frac{Q_{ult}L}{A_P E_P} \tag{3.49}$$

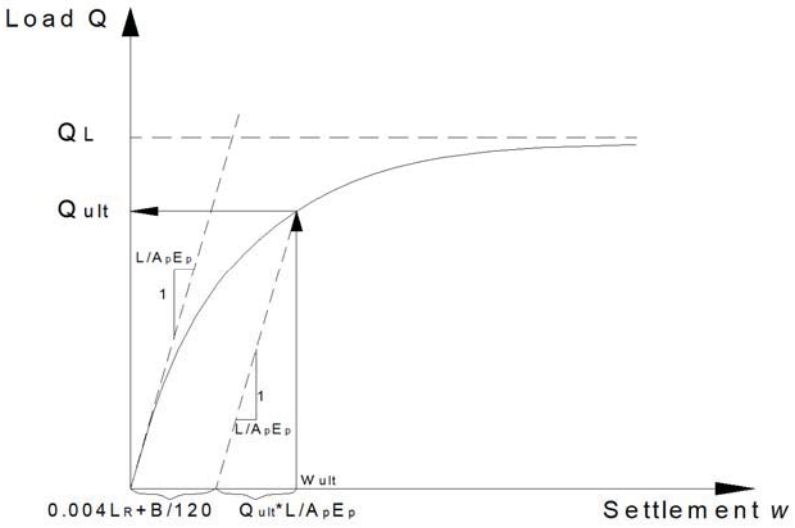


Figure 3.19 Graphical representation of Davisson's criterion

where:

Q_{ult}= ultimate load

w_{ult}=settlement (in the same unit as L_r) observed for the pile when $Q=Q_{ult}$

L_r = reference length =1m

B= pile diameter (or width) in the same units as L_r

Ap = cross sectional area of the pile (in unit of L_r)

E_p = pile Young's modulus (in units consistent with those of load and length)

L = pile length in the same unit as L_r

Davisson's criterion was used in the NCHRP report-507 by Paikowsky et al. (2004), and was found to perform best overall. One of the main advantages of this method is that it is an objective method and it can be used as an acceptance criterion

for the static load test. However, Hannigan et al. (2005) supposed some limitations of this method, as it under-predicts the pile capacity for piles with diameters larger than 24 inches.

3.5.2 The Limited Total Settlement Methods

The Limited Total Settlement methods, $\Delta = 25.4$ mm and $\Delta = 0.1B$ (Terzaghi, 1942), define the failure load as the load corresponding to settlements of 25.4 mm and 0.1B, respectively, where B is the diameter of the pile. These methods are not applicable in many cases. For example, the elastic compression for a very long steel pile often exceeds 25.4 mm and/or 0.1B without inducing any plastic deformation in the soil.

3.5.3 DeBeer's Method

DeBeer (1970) defines the failure load as the load corresponding to the intersection of two distinct slopes created by the load-settlement data plotted using logarithmic scales. The two slopes are especially visible for piles that experience plunging failures, yet when using DeBeer's method piles that undergo local failures, the result may be a range of values, such as illustrated here

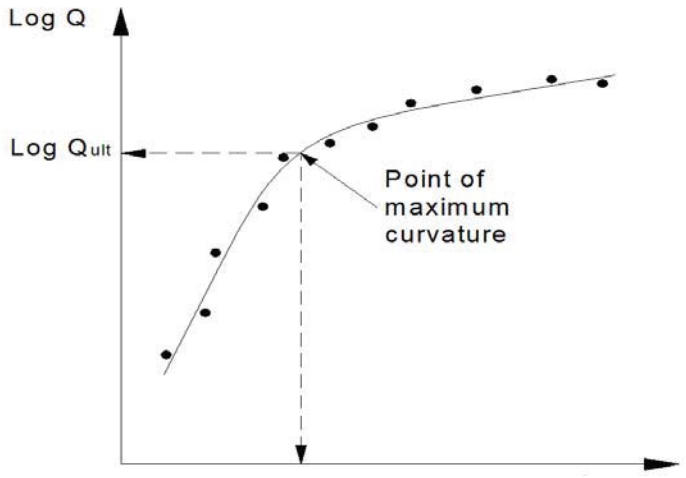


Figure 3.20 Graphical representation of DeBeer method

3.5.4 Chin's Method (1970) for Estimate the Ultimate Load of Piles from the Test not Carried to Failure

It is usually very expensive and often impractical to extend a load test on a large pile or a pile group until collapse .The ultimate load of a pile can be obtained from the results of a load test without having to load the pile to failure. The Chin's method (1970) is base on the results of an experiment study of the shear deformation characteristics obtained from shear box and triaxial tests and from the tests carried out with the model piles in both the field and in laboratory. The load test show that the deformation and load relation ship is hyperbolic and the plot of $\frac{w(deformation)}{P(load)}$ versus w(*deformation)* is liner and the inverse of this line therefore gives the ultimate value of load P (Chin 1970)

The pile load-settlement (Q-w) curve can be express by following equation:

$$Q = \frac{w}{a + bw} \tag{3.50}$$

Where a and b are constant with very specific physical meanings

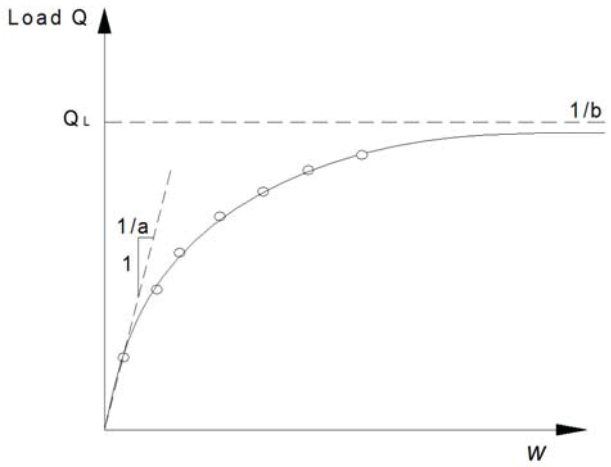


Figure 3.21a Load-settlement curve

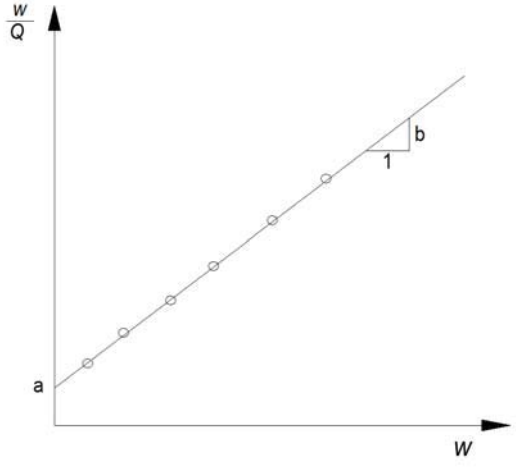


Figure 3.21b Replotted results for determination of C_1 and Q_L

If we rewrite equation (3.50) as

$$Q = \frac{w}{a + bw} = \frac{1}{\frac{a}{w} + b} \tag{3.51}$$

As the settlement w approaches infinity, Q approaches 1/b. And by definition the load at infinite settlement is the ultimate load Q_{ult} so it follows that

$$Q_{ult} = \frac{1}{b} \tag{3.52}$$

If dividing Q/w, we obtain the equation for the pile head stiffness K_t

$$K_t = \frac{Q}{w} = \frac{1}{a + bw} \tag{3.53}$$

As w=0, $K_t = \frac{1}{a}$ is the initial pile head stiffness

The flowing equation will be used for plotting the $\frac{w(deformation)}{P(load)}$ versus w

$$\frac{w}{Q} = bw + a = \frac{1}{Q_{ult}} w + \frac{1}{K_{t(w=0)}} \tag{3.54}$$

From plotting we find out the Q_{ult} of static load test of pile.

3.6 Soil Properties Correlated from Insitu Tests

Most of the static methods directly or indirectly utilize the soil shear strength parameters when calculating the capacity of pile foundations. These parameters could be determined using laboratory tests or correlations to field tests such as the SPT or CPT. From the Iowa's survey result (2008), 94% of the respondents claimed to be using the Standard Penetration Test (SPT), 52% use the Cone Penetration Test (CPT), 16% follow the Vane Shear Test (VST), and around 20% perform other methods. The survey confirmed that the majority of respondents depend on SPT or CPT tests to determine the basic soil parameters.

The SPT has been used in correlations for soil unit weight (γ), relative density (Dr), angle of internal friction (ϕ), and unconfined compressive strength (Su). There

are several correlations between the SPT N-values and different soil parameters and presented in Table 3.8. According to Paikowsky et al. (2004), the best correlation for determining ϕ in cohesionless soils is provided by Peck Hanson and Thornburn (1974), and it is recommended to limit ϕ below 36°. The most common correlation used to estimate the Su from SPT is also the one provided by Terzaghi and Peck (1967) using the uncorrected N-values. Tables 3.7a and 3.7b after Bowles (1977) summarize different ranges of Dr, ϕ, q_u and γ with respect to corrected and uncorrected N-values, respectively. On the other hand, there are many empirical correlations to estimate the soil shear strength parameters from the CPT test. As shown in Table 3.9, the Su and ϕ were mainly calculated based on the CPT cone tip resistance (q_c), as well as the soil effective overburden pressure (σ'_v). According to Paikowsky et al. (2004), the best correlation for determining Su is by Hara (1974), while the correlation used by Robertson and Campanella (1983) was most commonly used for calculating the soil internal friction angle.

Table 3.10a: Correlations between SPT N-values and Dr, ϕ, and γ soil (after Bowles, 1977)*

Description	Very Loose	Loose	Medium	Dense	Very Dense
Corrected SPT N-value	0 to 4	4 to 10	10 to 30	30 to 50	50+
Relative density, Dr	0 – 0.15	0.15 – 0.35	0.35 – 0.65	0.65 – 0.85	0.85 – 1.00
Internal friction Angle, ϕ	25 – 30°	27 – 32°	30 – 35°	35 – 40°	38 – 43°
Unit weight, γ (kN/m3)	11.0 – 15.7	14.1 – 18.1	17.3 – 20.4	17.3 – 22.0	20.4 – 23.6

*Use 5% larger values for granular material.

Table 3.10b: Correlations between SPT N-values and qu and γ (after Bowles, 1977)*

Description	Very soft	Soft	Medium	Stiff	Very Stiff	Hard
Un-corrected SPT N-value	0 to 2	2 to 4	4 to 8	8 to 16	16 – 32	32+
Su (kPa)	0 – 24	24 – 48	48 – 96	96 – 192	192 – 384	384+
γ (kN/m3)	15.8 – 18.8	15.8 – 18.8	17.3 – 20.4	18.8 – 22.0	18.8– 22.0	18.8 – 22.0

*Correlations should be used for preliminary estimates only

3.6.1 Correlations of Soil Properties from SPT

3.6.1.1 Undrained Shear Strength Su

Terzaghi and Peck (1967): $Su/p_a = 0.06\ N$ (3.53)

Hara (1974): $Su/p_a = 0.29\ N^{0.72}$ (3.54)

where: N is the uncorrected blow counts

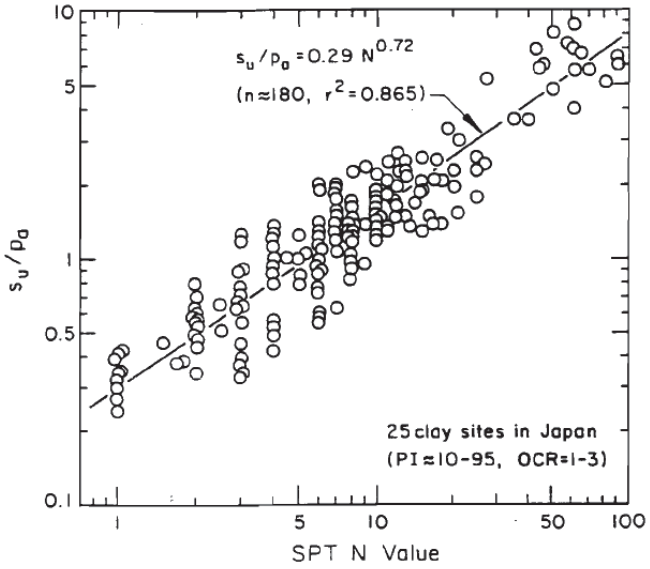


Figure 3.22 Su-SPT N Relationships by Hara 1974

(Kulhawy and Mayne, 1990)

3.6.1.2 OCR for Clay

Mayne and Kemper: $OCR = 0.58\ Np_a / \sigma'_o$ (3.55)

where: N is the uncorrected blow counts

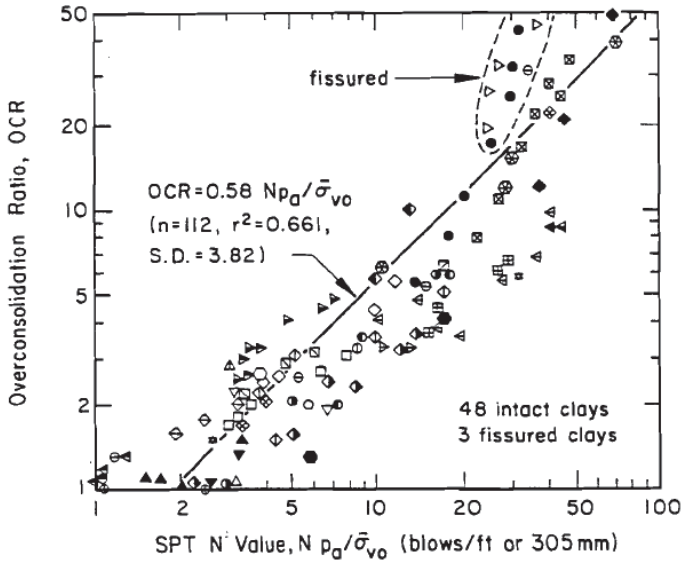


Figure 3.23 OCR-N Relationships (Kulhawy and Mayne, 1990)

3.6.1.3 The Effective Stress Friction Angle for Cohesionless Soil

Peck, Hanson and Thornburn:

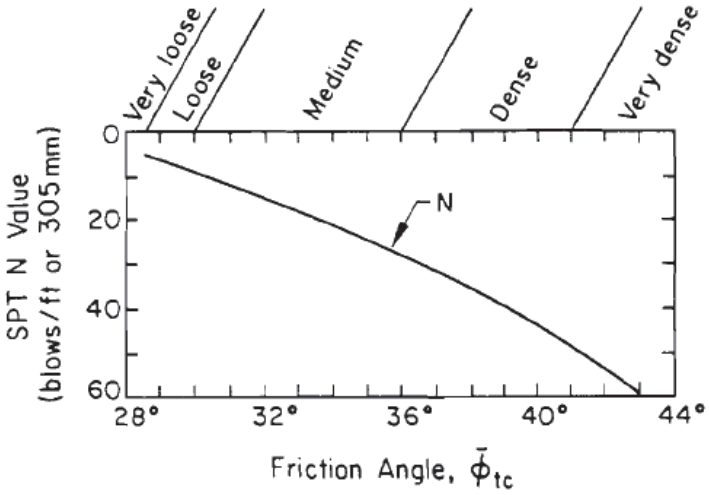


Figure 3.24 φ'-N Relationships by Peck, Hanson and Thornburn (Kulhawy and Mayne, 1990)

Schmertmann:

$$\varphi' \approx \tan^{-1} [N / (12.2 + 20.3\ \sigma'_{vo}/p_a)]^{0.34} \qquad (3.57)$$

where: N is the uncorrected blow count, σ_{vo}': vertical stress

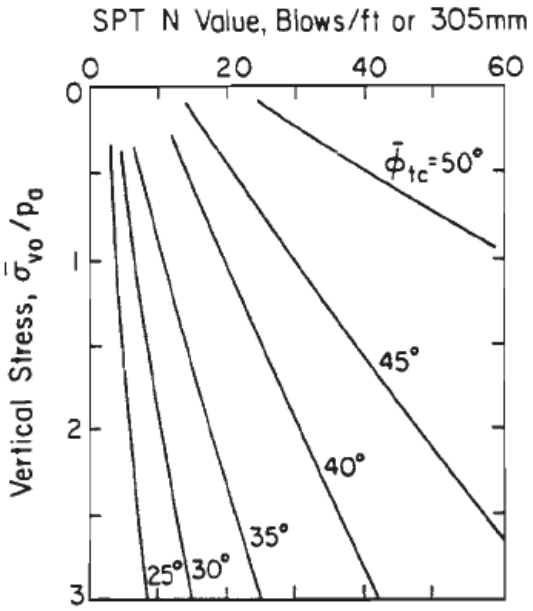


Figure 3.25 φ'-N Relationships by Schmertmann (Kulhawy and Mayne, 1990)

3.6.1.4 Relative Density D_r of Cohensionless Soil

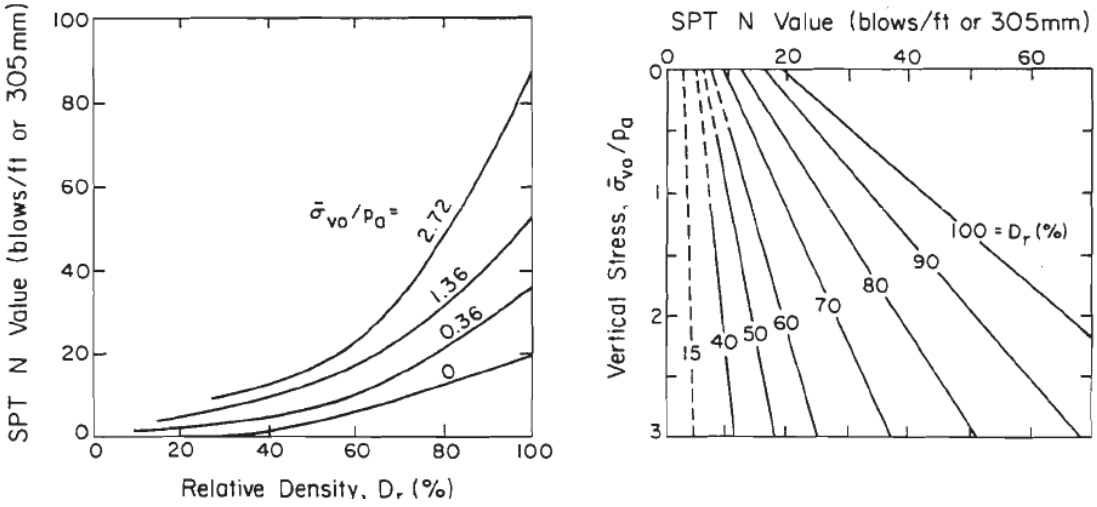


Figure 3.26 Relative Density--N--Stress Relationships

(Kulhawy and Mayne, 1990)

Table: 3.11 Summary correlations between SPT N-values and soil parameters

Soil Properties	SPT – N value Correlation	Reference
φ	54 - 27.6 exp(-0.014N')	Peck, Hanson and Thornburn (1974)
	$\tan^{-1}$ [N / (12.2 + 20.3 σ')] $^{0.34}$	Schmertmann (1975)
S_u (bar)	0.06 N	Terzaghi and Peck (1967)
	0.29 $N^{0.72}$	Hara (1974)
OCR for clay	0.5 N / σ'$_o$ (σ'$_o$ in bar)	Mayne and Kemper
Dr	Gibbs and Holtz's Figures	Kulhawy and Mayne, 1990

3.6.2 Correlations of Soil Properties from CPT

3.6.2.1 Undrained Shear Strength S_u

The theoretical relationship for the cone tip resistance in clay is given by:

$$S_u/p_a = (q_c - \sigma_o) /N_k \qquad (3.58)$$

where: q_c= cone tip resistance, σ_o= total overburden stress and N_k= cone bearing factor. The application of classical plastic theory to this bearing capacity problem suggests N_k=on the order of 9 for general shear model

3.6.2.2 OCR for Cohesive Soil - Mayne

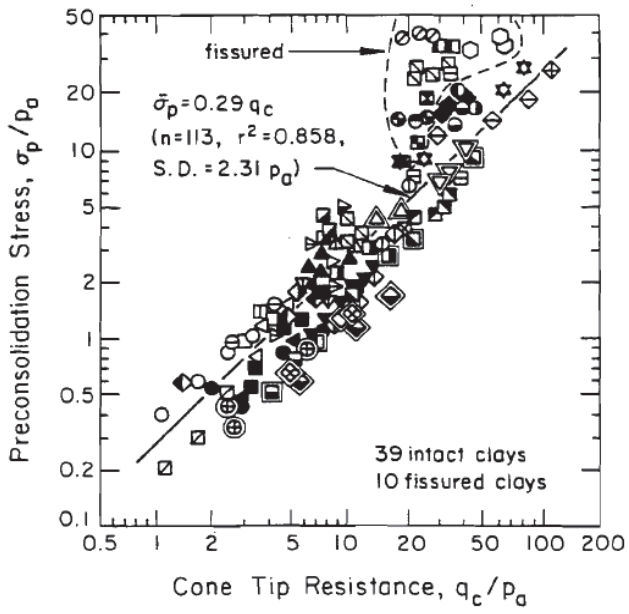


Figure 3.27 σ_p-q_c Relationships (OCR = σ_p / σ'$_0$) (Kulhawy and Mayne, 1990)

The cone penetration test (CPT) tip resistant, q_c, has been used effectively to profile the preconsolidation stress in clay. Figure presents the available data from 49 clays.

$$OCR = 0.29\ q_c / \sigma'_o \qquad (3.59)$$

where: q_c= cone tip resistance, σ_o= total overburden stress

3.6.2.3 The Effective Stress Friction Angle for Cohensionless Soil Robertson and Campanella

$$\phi' = \tan^{-1}(0.1+0.38\log(q_c/\sigma_{vo}')) \qquad (3.60)$$

where: q_c= cone tip resistance

σ_o= total overburden stress

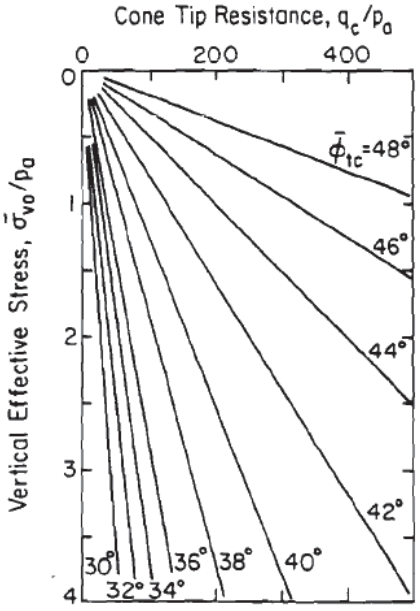


Figure 3.28 φ'_{tc} correlated from q_c for NC, uncemented quartz sands (Kulhawy and Mayne, 1990)

3.6.2.4 Relative Density D_r of Cohensionless Soil- Jamiolkowski

$$\text{Dr}\,(\%) = 68\left[\log\left(\frac{q'_c}{\sqrt{p_a\sigma'_0}}\right) - 1\right] \tag{3.61}$$

$$q'_c = \frac{q_c}{0.9 + D_r/300}$$

where: q_c= cone tip resistance, σ_o= total overburden stress

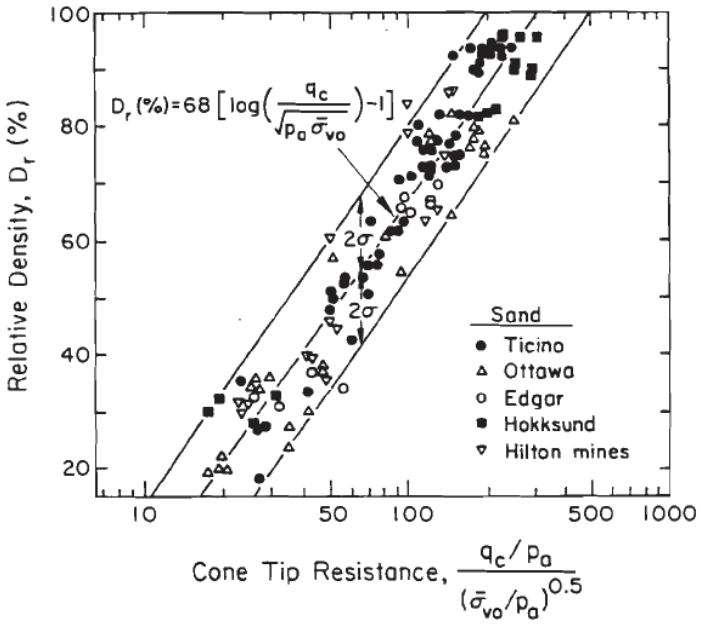


Figure 3.29 Correlation between Dr and qc by Jamiolkowski (uncorrected for boundary effect) (Kulhawy and Mayne, 1990)

Table 3.12 Summary Correlations between CPT and soil parameters

Properties	**From CPT**	**Reference**
φ (deg.)	atan(0.1+0.38*Log(q_c/σ'))	Robertson and Campanella (1983)
S_u (bar)	(q_c - σ_o) / N_k ; q_c and σ_o in bars.	Hara (1974)
OCR for clay	0.29 q_c / σ'$_o$; q_c and σ_o in bars.	Mayne
Dr	68 log(q_{cn}) – 68 ; $q_{cn} = \frac{q'_c}{\sqrt{P_a\sigma'_0}}$ $q'_c = q_c / K_q$, K_q = 0.9 + Dr/300, q_c and σ'$_o$ in bars.	Jamiolkowski

3.6.3 Soil Properties Correlated from Laboratory Tests

For cohesive soils, Atterberg limits and their relationship to the in-situ water content are most commonly used for such correlations. Figure 3.30 shows one correlation between the Liquidity Index, LI, and the ratio of undrained shear strength to vertical effective stress level in triaxial compression, Su/σ'vo.

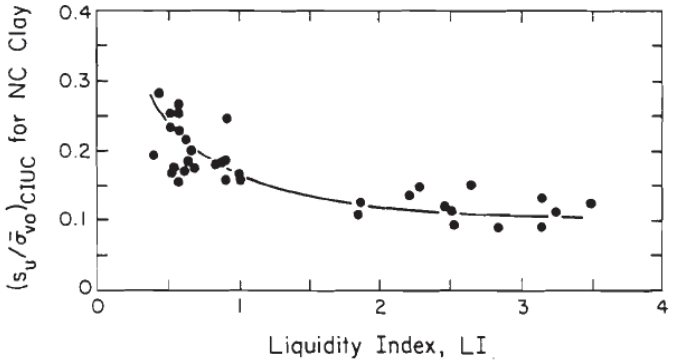


Figure 3.30 Correlation between Normalized Undrained Shear Strength and Liquidity Index for NC Clays (after Kulhawy and Mayne, 1990)

4. Determination of Resistance Factors by Calibration

4.1 Calibration by fitting ASD to LRFD

Calibration by fitting to ASD is used if the data required for the statistical analysis is not available. In this case, the LRFD resistance factors obtained by fitting to the ASD method should be only used as a benchmark to provide the same degree of safety that was provided by the ASD. However, this does not satisfy the LRFD reliability based requirements.

Divide the LRFD equation: $\Phi R_n = \sum \eta_i \gamma_i Q_i$ by the ASD equation: $R_n = Fs \sum Q_i$

$$\frac{\phi R_n}{R_n} = \frac{\sum \eta_i \gamma_i Q_i}{FS \times \sum Q_i} \tag{4.1}$$

From which, with $\eta i = 1.0$

$$\phi = \frac{\sum \gamma_i Q_i}{FS \times \sum Q_i} \tag{4.2}$$

If the loads consist only of dead load Q_D and live load Q_L, then Eq (4.2) becomes

$$\phi = \frac{\gamma_D D_D + \gamma_L D_L}{FS(Q_D + Q_L)} \rightarrow \phi = \frac{\gamma_D \dfrac{D_D}{D_L} + \gamma_L}{FS(\dfrac{D_D}{D_L} + 1)} \tag{4.3}$$

Table 4.1 shows the resistance factors, calibrated by fitting with ASD after McVay et al., 1998; depend on the DL to LL ratio. The DL/LL ratio could range between 1.0 and 4.0 for bridge structures depending on the bridge span and other factors. Barker et al., (1991), recommended a DL/LL ratio of 3.0 for bridge structures and Paikowsky et al., (2004), suggested that the ratio should be within the range of 2.0 to 2.5, since it is reasonable and applicable for long span bridges. According to Allen (2005) and Paikowsky et al. (2004), the DL/LL ratio has a small influence on the LRFD resistance factors when calibrated based on the reliability theory. Allen (2005) considered a DL/LL

ratio of 3.0 to be consistent with the previous work done by Barker (1991), and thus it can directly compare with the developed resistance factors

Table 4.1 Resistance Factors Calibrated by Fitting with ASD for $\gamma_D = 1.25$ and $\gamma_L = 1.75$ (After McVay et al., 1998).

QD/QL	Resistance Factor, FS					
	FS=1.5	FS=2.0	FS=2.5	FS=3.0	FS=3.5	FS=4.0
1	1.00	0.75	0.60	0.50	0.43	0.38
2	0.94	0.71	0.57	0.47	0.40	0.35
3	0.92	0.69	0.55	0.46	0.39	0.34
4	0.90	0.68	0.54	0.45	0.39	0.34
5	0.89	0.67	0.53	0.44	0.38	0.33
6	0.88	0.66	0.53	0.44	0.38	0.33
7	0.88	0.66	0.53	0.44	0.38	0.33
8	0.87	0.65	0.52	0.44	0.37	0.33
9	0.87	0.65	0.52	0.43	0.37	0.33
Median	0.94	0.70	0.56	0.47	0.39	0.34
Recommended	0.90	0.65	0.55	0.45	0.35	0.30

4.2 Calibration by Using Reliability Theory

The objective of the reliability theory is to limit the probability of failure (Pf), probability of loads exceeding the resistances, of structures to a certain acceptable extent. As shown in Figure 4.1, Q and R are two PDFs representing the loads and resistances, respectively and the area of overlap between the two PDFs is considered as failure. By subtracting the two PDFs (R - Q), the area to the left of the zero axis is considered to be the failure region and the probability of failure can be determine by using the reliability index (β). The reliability index stands for the number of standard deviations (σ) representing the distance between the zero axis and the mean of R - Q. The general process used by Barker, et al. (1991) and Paikowsky, et al. (2004) to develop the regionally calibrated LRFD resistance factors based on the reliability theory is as follows:

- Collect data required for statistical analysis

- Calculate statistical parameters for load and resistance PDFs: the Mean, Standard Deviation, and Coefficient of Variation (COV)
- Determine the best-fit distribution for each PDF
- Choose the appropriate statistical method for calibration (FOSM, FORM, Monte Carlo Simulation Method)
- Use the recommended load factors provided in the design code
- Select a reliability index β based on the margin of safety required in design specifications, and by considering the recommended levels of reliability used for geotechnical designs
- Calculate resistance factors for design

4.2.1 Load, Resistance Bias Factor

The load, resistance bias factor is defined as:

$$\lambda_{R_i(orQ_i)} = \frac{R_m(orQ_m)}{R_n(orQ_n)} \tag{4.4}$$

where: R_m = measured resistance, Q_m = measured load

R_n = predicted resistance, Q_n = predicted load

The mean, standard deviation and coefficient of variation of the set of bias data $\lambda_{Ri(or\ Qi)}$ are:

Mean: $$\mu_{R(orQ)} = \frac{\sum \lambda_{Ri(orQ_i)}}{N} \tag{4.5}$$

Standard deviation: $$\sigma_{R(orQ)} = \sqrt{\frac{\sum \left(\lambda_{Ri(orQi)} - \mu_{R(orQ)}\right)^2}{N-1}} \tag{4.6}$$

Coefficient of variation: $$COV_{R(orQ)} = \frac{\sigma_{R(orQ)}}{\mu_{R(orQ)}} \tag{4.7}$$

The bias factors and coefficients of variation for load components can be developed in a fairly straightforward manner. Physical measurements can be made of various

weights of materials and their statistics calculated. Vehicle live loads and their variations can be measured without interference to vehicles using weigh-in-motion instrumentation. From this load data, the load statistics can be compiled and tabulated.

The results of statistical analysis of highway dead and live loads are summarized in Table 4.2 (Nowak, 1993). The largest variation is the weight of the wearing surface placed on bridge decks. Also of interest, as indicated by the bias factor, is that the observed actual loads are greater than the specified nominal values.

Table 4.2 λ_{QD}, λ_{QL}, COV_{QD}, COV_{QL} as recommended by AASHTO (cited in Withiam etal., 1997)

Load component		λ	COV
Dead load ($_{QD}$)	Factory-made	1.03	0.08
	Cast in Place (CIP)	1.05	0.10
	Asphalt wearing surface	1.00	0.25
Live load ($_{QL}$)		1.15	0.18

4.2.2 Probability Density Function

Based on the distribution of the resistance data, a lognormal probability distribution was recommended for the resistance data by the AASHTO Specification. Equation (4.8) presents the lognormal probability density equation using to calibrate the resistance factor for depth foundation in design.

$$f(x) = \frac{1}{\sqrt{2\pi}\xi x}\exp\left[-\frac{1}{2}\left(\frac{\ln x - \lambda}{\xi}\right)^2\right] \tag{4.8}$$

In Equation (4.8) the values of λ and ζ are the lognormal mean and lognormal standard deviation respectively,

$$\xi^2 = \ln\left(1 + \frac{\sigma^2}{\mu^2}\right) \tag{4.9a}$$

$$\lambda = \ln \mu - \frac{1}{2}\xi^2 \tag{4.9b}$$

Where: σ and μ are the standard deviation and the mean of the resistance or load as defined in prior sections.

4.2.3 The First Order Second Moment (FOSM) Method

In design practice, there are usually two types of limit states: ultimate limit states and serviceability limit state. Each can be represented by a performance function of the form, $g(X) = g(X_1, X_2, ..., Xn)$ in which X is a vector of basic random variables (X_1, X_2, ..., Xn) for strengths and loads. The performance function g(X) is sometimes called the limit state function. It relates the random variables for the limit-state of interest. The limit state is defined when g(X) = 0, and therefore, the failure occurs when g(X) < 0**.** This method uses the first terms of a Taylor series expansion of the performance function to estimate the expected value and variance of the performance function.

$$\begin{aligned} g(x_1, x_1, ..., x_n) &\approx g(\mu_{X1}, \mu_{X1}, ..., \mu_{Xn}) + \frac{1}{1!}\sum_{i=1}^{n}(x_i - \mu_{X1})\frac{\partial g}{\partial x_i} \\ &+ \frac{1}{2!}\sum_{i=1}^{n}\sum_{j=1}^{n}(x_i - \mu_{Xi})(x_i - \mu_{Xj})\frac{\partial^2 g}{\partial x_i \partial x_j} \\ &+ \frac{1}{3!}\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}(x_i - \mu_{Xi})(x_i - \mu_{Xj})(x_i - \mu_{Xk})\frac{\partial^3 g}{\partial x_i \partial x_j \partial x_k} + ... \end{aligned} \tag{4.10a}$$

By assuming all the $(x_i - \mu_{X_i})$ terms are small, their squares and cubes and higher powers will be smaller and can be ignored. Then, the first order terms give:

$$g(x_1, x_1, ..., x_n) \approx g(\mu_{X1}, \mu_{X1}, ..., \mu_{Xn}) + \sum_{i=1}^{n}(x_i - \mu_{X1})\frac{\partial g}{\partial x_i} \tag{4.10b}$$

Since only first order term is included, methods based on this assumption are called first order method. To find the expected value of g, it needs to integrate g multiplied by the joint probability density function of the variables X_1 through X_n from $-\infty$ to $+\infty$.

$$\mu_g = \int_{-\infty}^{+\infty} g(x_1, x_1, ..., x_n) f_{Xi}(x_i) dx_i \approx \int_{-\infty}^{+\infty} \left(g(\mu_{X1}, \mu_{X1}, ..., \mu_{Xn}) + \sum_{i=1}^{n} (x_i - \mu_{X1}) \right) f_{Xi}(x_i) dx_i \qquad (4.11)$$

Since $g(\mu_{X1}, \mu_{X1}, ..., \mu_{Xn})$ is constant, $\int_{-\infty}^{+\infty} f_{Xi}(x_i) dx_i = 1$ and $\int_{-\infty}^{+\infty} \sum_{i=1}^{n} (x_i - \mu_{X1}) f_{Xi}(x_i) dx_i = 0$

The expected value of g can be expressed by following equation:

$$\mu_g \approx g(\mu_{X1}, \mu_{X1}, ..., \mu_{Xn}) \qquad (4.12)$$

The variance of function g is:

$$Var[g] = \sigma_g{}^2 = E\left[(g - \mu_g)^2 \right] \qquad (4.13)$$

And from equation (4.10b) and (4.13)

$$\sigma_g{}^2 \approx E\left[\left(\sum_{i=1}^{n} (x_i - \mu_{X_i}) \frac{\partial g}{\partial x_i} \right)^2 \right] \qquad (4.14)$$

Multiplying the expression in brackets by probability density function and integrating over the complete range of probabilities leads to an expression for the variance:

$$\sigma_g{}^2 \approx \sum_{i=1}^{n} \sum_{j=1}^{n} \rho_{X_i X_j} \sigma_{X_i} \sigma_{X_j} \frac{\partial g}{\partial x_i} \frac{\partial g}{\partial x_j} \qquad (4.15)$$

$$\sigma_g{}^2 \approx \sum_{i=1}^{n} \sigma_{X_i}{}^2 \left(\frac{\partial g}{\partial x_i} \right)^2 + \sum_{i=1}^{n} \sum_{j \neq i}^{n} Cov(X_i, X_j) \frac{\partial g}{\partial x_i} \frac{\partial g}{\partial x_j} \qquad (4.16)$$

Since the variance in form of the second moment and is the highest order statistical result used in analysis, it is also called a second moment method.

If g is a linear function of the variable x_i:

$$g(x_1, x_1, ..., x_n) = a_1 x_1 + a_2 x_2 + ... + a_n x_n = \sum_{i=1}^{n} a_i x_i \qquad (4.17)$$

Mean and variance of function g could be expressed by following equation

$$\mu_g = a_1\mu_{X_1} + a_2\mu_{X_2} + ...+ a_n\mu_{X_n} = \sum_{i=1}^{n} a_i\mu_{X_i} \tag{4.18}$$

$$\sigma_g{}^2 = \sum_{i=1}^{n}\sum_{j=1}^{n} a_i a_j \rho_{X_i X_j}\sigma_{X_i}\sigma_{X_j} \tag{4.19}$$

4.2.3.1 Reliability indexβ

If the performance function g has two variables which are load Q and resistant R:

$$g = R - Q \tag{4.20}$$

from the equation (4.18) and (4.19), the mean and variance of g is

$$\mu_g = \mu_R - \mu_Q \tag{4.21}$$

$$\sigma_g{}^2 = \sigma_R{}^2 + \sigma_Q{}^2 - 2\rho_{RQ}\sigma_R\sigma_Q \tag{4.22}$$

The reliability index, β, is defined as:

$$\beta = \frac{\mu_g}{\sigma_g} = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R{}^2 + \sigma_Q{}^2 - 2\rho_{RQ}\sigma_R\sigma_Q}} \tag{4.23}$$

If the load and resistance are uncorrelated, the correlation coefficient is zero and

$$\beta = \frac{\mu_g}{\sigma_g} = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R{}^2 + \sigma_Q{}^2}} \tag{4.24}$$

In this study, the load (Q) and the resistance (R), are assumed to be lognormally distributed. The limit state function in this case is defined as:

$$g\,(R, Q) = \ln\,(R) - \ln\,(Q) = \ln\,(R/Q) \tag{4.25}$$

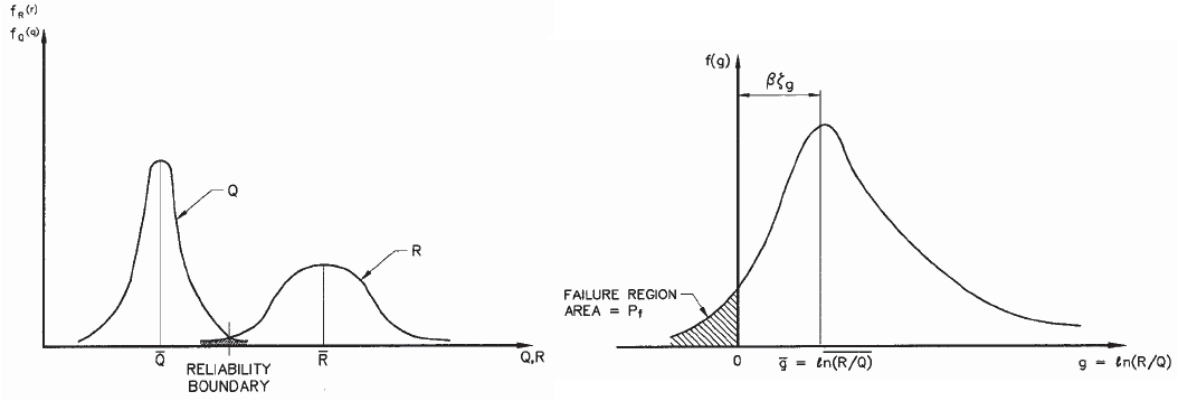


Figure 4.1 Distribution of load and resistance and reliability index, β

Since R and Q are lognormally distributed, ln(R) and ln(Q) are normal distribution. Thus, the mean value of g (R, Q) can be expressed as:

$$\overline{g} = \overline{\ln(R)} - \overline{\ln(Q)} \tag{4.26}$$

Where:

$$\overline{\ln(R)} = \ln(\overline{R}) - \frac{1}{2}\ln(1+COV^2{}_R) = \ln(\overline{R}) - \ln(1+COV^2{}_R)^{0.5}$$

$$\overline{\ln(R)} = \ln\frac{\overline{R}}{\sqrt{1+COV^2{}_R}} \tag{4.27}$$

$$\overline{\ln(Q)} = \ln(\overline{Q}) - \frac{1}{2}\ln(1+COV^2{}_Q) = \ln(\overline{Q}) - \ln(1+COV^2{}_Q)^{0.5}$$

$$\overline{\ln(Q)} = \ln\frac{\overline{Q}}{\sqrt{1+COV^2{}_Q}} \tag{4.28}$$

From equation (4.26), (4.27) and (4.28)

$$\overline{g} = \ln\frac{\overline{R}}{\sqrt{1+COV^2{}_R}} - \ln\frac{\overline{Q}}{\sqrt{1+COV^2{}_Q}} = \ln\frac{\dfrac{\overline{R}}{\sqrt{1+COV^2{}_R}}}{\dfrac{\overline{Q}}{\sqrt{1+COV^2{}_Q}}} = \ln\left(\frac{\overline{R}}{\overline{Q}}\frac{\sqrt{1+COV^2{}_Q}}{\sqrt{1+COV^2{}_R}}\right)$$

$$\text{or} \qquad \overline{g} = \ln\left(\frac{\overline{R}}{\overline{Q}}\sqrt{\frac{1+COV^2{}_Q}{1+COV^2{}_R}}\right) \tag{4.29}$$

And its standard deviation is:

$$\varsigma_g = \sqrt{\sigma^2_{\overline{\ln(R)}} + \sigma^2_{\overline{\ln(Q)}}} \tag{4.30}$$

where:

$$\sigma^2_{\overline{\ln(R)}} = \ln(1 + COV^2{}_R) \tag{4.31a}$$

$$\sigma^2_{\overline{\ln(Q)}} = \ln(1 + COV^2{}_Q) \tag{4.31b}$$

From equation (4.30), (4.31a) and (4.31b)

$$\varsigma_g = \sqrt{\ln(1 + COV^2{}_R) + \ln(1 + COV^2{}_Q)}$$

or

$$\varsigma_g = \sqrt{\ln(1 + COV^2{}_R)(1 + COV^2{}_Q)} \tag{4.32}$$

where :

$\overline{R}$ and $\overline{Q}$: mean values of resistance and load

COV_R, COV_Q : coefficient of variation of R and Q

The reliability index β is defined as the ratio between the lognormal mean, $\overline{g}$, and the lognormal standard deviation, ξ, of the $\overline{\ln(R/Q)}$ series:

$$\beta = \frac{\overline{g}}{\xi_g} \text{ or } \overline{g} = \beta * \xi g$$

$$\beta = \frac{\overline{g}}{\xi_g} = \frac{\ln\left[(\overline{R}/\overline{Q})\sqrt{(1 + COV^2{}_Q)/(1 + COV^2{}_R)}\right]}{\sqrt{\ln(1 + COV^2{}_Q)(1 + COV^2{}_R)}} \tag{4.33}$$

The mean values of the load resistance can be expresses in terms of nominal load and resistance and their respective bias factors such that: $\overline{Q} = \lambda_Q Q_n$ and $\overline{R} = \lambda_R R_n$

The equation (4.33) can be written as:

$$\beta = \frac{\ln\left[\left(\lambda_R R_n / \lambda_Q Q_n\right)\sqrt{(1 + COV^2{}_Q)/(1 + COV^2{}_R)}\right]}{\sqrt{(1 + COV^2{}_R)/(1 + COV^2{}_Q)}} \tag{4.34}$$

Rn and Qn can be expressed in terms of factor of safety (FS) such that $R_n = FS \times Q_n$ Consider the load combination of dead load (Q_D) and live load (Q_L) for AASHTO Strength Case I. Then, $\lambda_Q Qn = \lambda_{QD} Q_D + \lambda_{QL} Q_L$ and $Rn = FS\,(Q_D + Q_L)$.

Also, Q_D and Q_L are assumed to be mutually independent and $COV_Q^2 = COV_{QD}^2 + COV_{QL}^2$ Therefore, Equation (4.34) can be rewritten in the following format:

$$\beta = \frac{\ln\left[\frac{\lambda_R FS(Q_D + Q_L)}{\lambda_{QD}Q_D + \lambda_{QL}Q_L}\sqrt{(1+COV_{QD}^2 + COV_{QL}^2)/(1+COV_R^2)}\right]}{\sqrt{\ln(1+COV_R^2)(1+COV_{QD}^2+COV_{QL}^2)}} \quad (4.36)$$

Or can be written as

$$\beta = \frac{\ln\left[\frac{\lambda_R FS(Q_D/Q_L + 1)}{\lambda_{QD}Q_D/Q_L + \lambda_{QL}}\sqrt{(1+COV_{QD}^2 + COV_{QL}^2)(1+COV_R^2)}\right]}{\sqrt{\ln(1+COV_R^2)(1+COV_{QD}^2+COV_{QL}^2)}} \quad (4.37)$$

It is seen from this equation that the reliability index is a function of FS, Q_D/Q_L, the load statistics (λ_{QD}, λ_{QL}, COV_{QD}, COV_{QL}) and the resistance statistics (λ_R, COV_R). Hansell and Viest, 1971 developed the following empirical equation for the Q_D/Q_L ratio:

$$Q_D/Q_L = (1+ IM) * 0.0132\ L \quad (4.38)$$

Where: IM = Dynamic load allowance factor (usually equal to 0.33)

L = Span length (feet)

Q_D/Q_L usually ranges from 1.0 to 3.0 (corresponding to L = 57-170 ft).

In LRFD specifications, the targeted reliability index (β) is defined as the measure of safety associated with a probability of failure (P_f). The probability of failure represents the probability of the condition, at which the resistance multiplied by the resistance factors will be less than the load multiplied by the load factors. A very precise definition of probability of failure, pf, is in terms of reliability index, Fu(β) (Withiam et al. 1997).

$$p_f = 1 - F_u(\beta) \quad (4.39)$$

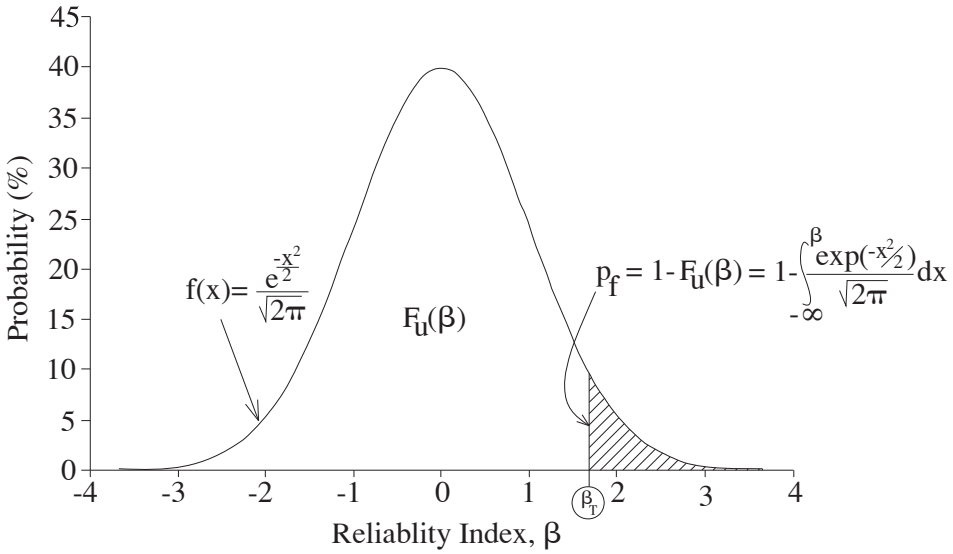


Figure 4.2 Reliability definition based on standard normal probability density function

$F_u(x)$ is the standard normal cumulative distribution function.

$$F_u(\beta) = 1 - \int_{\beta}^{\infty} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}x^2\right) dx \qquad (4.40)$$

The shaded area in Figure (4.2) represents the probability of failure, p_f, to achieve a target reliability index, β_T.

Table 4.3 Relationship between Probability of Failure and Reliability Index for Lognormal Distribution (After Withiam et al., 1997).

Reliability Index β	Probability of Failure pf	Probability of Failure pf	Reliability Index β
2.5	0.99×10^{-2}	10^{-1}	1.96
3.0	1.15×10^{-3}	1.10^{-2}	2.50
3.5	1.34×10^{-4}	1.10^{-3}	3.03
4.0	1.56×10^{-5}	1.10^{-4}	3.57
4.5	1.82×10^{-6}	1.10^{-5}	4.10
5.0	2.12×10^{-7}	1.10^{-6}	4.64
5.5	2.46×10^{-8}	1.10^{-7}	5.17

Another commonly accepted relationship between the reliability index, β, and the probability of failure, p_f, has been developed by Rosenblueth and Esteva (1972) using the relationship for values between 2 and 6.

$$pf = 460\, e(-4.3\beta) \qquad (2 < \beta < 6) \tag{4.41}$$

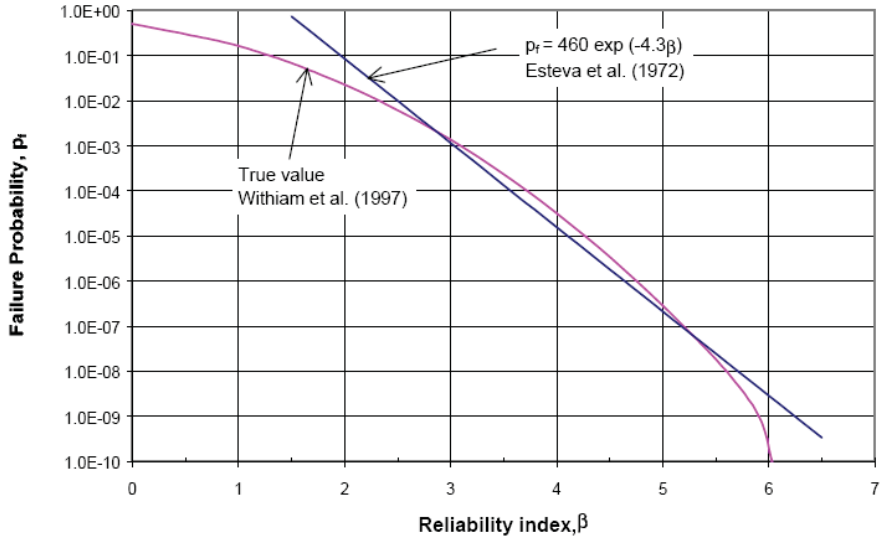


Figure 4.3 Comparison of Esteva and Withiam methods to obtain reliability index, β

For civil engineering project, β usually ranges from 2.0 to 4.0. However, due to the redundancy of pile groups, AASHTO and FHWA recommend using β from 2.0 to 3.0 for pile foundations (cited in Withiam et al., 1997), and it is called the target reliability index β_T.

4.2.3.2 Recommended Target Reliability Index

For depth foundation design, the target reliability index, β_T, could range from 2.5 to 3.0, which is corresponding to the range of approximate failure possibility of 1% to 0.1%, according to Barker et al. (1991a). However, Paikowsky, et al. (2004) indicated the more accurate failure probability for target reliability index of 2.5 and 3.0 is 0.62% and 0.14%, respectively. Additionally, for axially loaded pile, Paikowsky, et al. (2004) recommended a β_T of 2.33, which is corresponding to failure probability of 1%, for redundant piles, defined as 5 or more piles per pile cap, and a β_T of 3.0 for non-redundant piles, defined as 4 or less piles per pile cap.

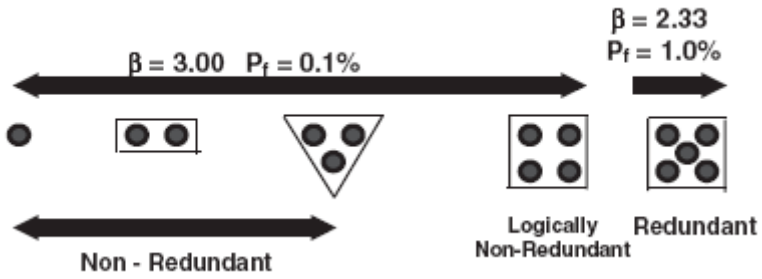


Figure 4.4 Redundant vs. non-redundant pile support, Paikowsky, et al. (2004)

4.2.3.3. Efficiency of Different Methods

McVay (2000) suggested an efficiency factor to determine the efficiency of different static methods that are relative to the actual pile behavior and to each other. This efficiency factor (φ/λ) is equal to the ratio of the resistance factor to the mean bias of the method. The φ/λ factor ranges from 0 to 1.0, in which a higher φ/λ is proportional to a higher efficiency. The efficiency factor reflects the economy of the design. The efficiency of a static method is not dependent on the corresponding LRFD resistance factor. For example, the factored pile design capacity, calculated using a specific static method, can be lower than that calculated using another static method, although the resistance factor of the first method may be higher than the second. This is essential because the first method might be underestimating the nominal pile capacity, while the second method could be overestimating it. By multiplying both methods with the corresponding LRFD resistance factors, the method with the lower resistance factor could yield a higher pile capacity overall.

4.2.3.4 Equivalent Factor of Safety

The economy of the LRFD resistance factors can also be measured by means of the equivalent factor of safety (FS) corresponding to the ASD. This equivalent FS is calculated based on the simplified relation provided in equation in Chapter 2. The equivalent FS is presented for each group based on a DL/LL = 2, $\gamma L = 1.75$, and $\gamma D =$

1.25, the FS=1.4167/φ. On the other hand, the actual FS is calculated by multiplying the mean bias by the equivalent FS. The actual FS represents the overall economy of the method, meaning that whenever the actual FS is lower, the foundation cost is reduced and vice versa.

4.2.3.5 Resistance Factor Calibration

The basic equation for LRFD was expressed as equation (2.2) and is rewritten here in the following format:

$$\phi = \frac{\sum \gamma_i Q_i}{R} \tag{4.42}$$

The nominal resistance R can be replace by the mean value ($\overline{R}$) and the resistance bias factor (λ_R) then,

$$\phi = \frac{\lambda_R \left(\sum \gamma_i Q_i\right)}{\overline{R}} \tag{4.43}$$

From equation (4.33) $\overline{R}$ can be replaced by the following equation:

$$\overline{R} = \frac{\overline{Q}\exp(\beta\sqrt{\ln\left[\left(1+COV_R{}^2\right)\left(1+COV_Q{}^2\right)\right]}}{\sqrt{\left(1+COV_Q{}^2\right)/\left(1+COV_R{}^2\right)}} \tag{4.44}$$

The equation (4.44) can be rewritten in the following form:

$$\phi = \frac{\lambda_R \left(\sum \gamma_i Q_i\right)\sqrt{\left(1+COV_Q{}^2\right)/\left(1+COV_R{}^2\right)}}{\overline{Q}\exp(\beta\sqrt{\ln\left[\left(1+COV_R{}^2\right)\left(1+COV_Q{}^2\right)\right]}} \tag{4.45}$$

The mean values of the load resistance can be expressed in terms of nominal load and resistance and their respective bias factors such that: $\overline{Q} = \lambda_Q Q_n$ and $\overline{R} = \lambda_R R_n$

$$\phi = \frac{\lambda_R \left(\gamma_{Q_L} Q_L + \gamma_{Q_D} Q_D\right)\sqrt{\left(1+COV_{Q_D}{}^2+COV_{Q_L}{}^2\right)/\left(1+COV_R{}^2\right)}}{\left(\lambda_{Q_L} Q_L + \lambda_{Q_D} Q_D\right)\exp(\beta\sqrt{\ln\left[\left(1+COV_R{}^2\right)\left(1+COV_Q{}^2\right)\right]}} \tag{4.46}$$

Diving the

$$\phi = \frac{\lambda_R \left(\gamma_{Q_D} \frac{Q_D}{Q_L} + \gamma_{Q_L} \right) \sqrt{\left(1 + COV_{Q_D}{}^2 + COV_{Q_L}{}^2\right) / \left(1 + COV_R{}^2\right)}}{\left(\lambda_{Q_D} \frac{Q_D}{Q_L} + \lambda_{Q_L} \right) \exp(\beta_T \sqrt{\ln\left[\left(1 + COV_R{}^2\right)\left(1 + COV_{Q_D}{}^2 + COV_{Q_L}{}^2\right)\right]}} \tag{4.47}$$

As recommend in AASHTO, the following parameters: dead load factor-γ_D = 1.25, live load factor-γ_L = 1.75, dead load bias factor-λ_{QD} = 1.08, live load bias factor-λ_{QL} =1.15, dead load coefficients of variation-COV_{QD} = 0.13 and live load coefficients of variation COV_{QL}= 0.18 could be used in equation 4.46 to calibrate the resistance factor ϕ. Sine dead to live load ratio Q_D/Q_L changes from 1-3 and has almost no effect on the resistance factor, this study uses Q_D/Q_L = 1.

4.2.4 First-Order Reliability Method (FORM) Analysis

The basic concepts and analytical procedures of the The First Order Reliability Method (FORM) methods were developed by Ditlevsen (1974), Ellingwood, et al. (1980), Hasofer and Lind (1974). The first step in the Hasofer-Lind approach is to reformulate the problem with dimensionless variables. If the performance function g has n uncertain variables (X_1, X_2,…X_n) and each variable X_i is defined in terms of its μ_{Xi} and its standard deviation σ_{Xi}, a primed variable, which is dimensionless and has the mean value of zero and unit standard deviation of primed variables could be defined by the following equation:

$$x'_i = \frac{x_i - \mu_{X_i}}{\sigma_{X_i}} \tag{4.48}$$

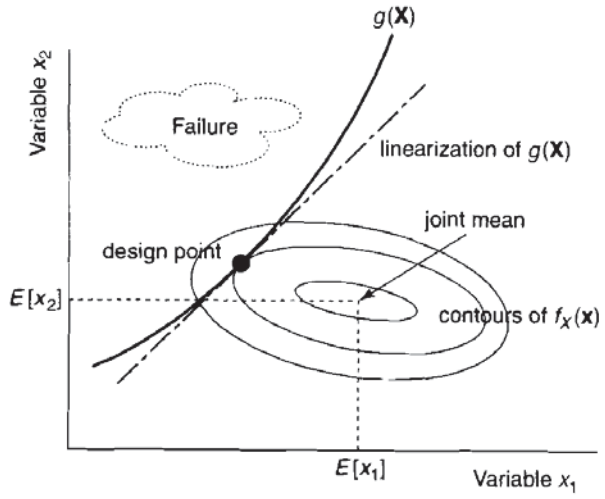


Figure 4.5 Limit state function and pdf of basic random variables (Baecher and Christian 2003)

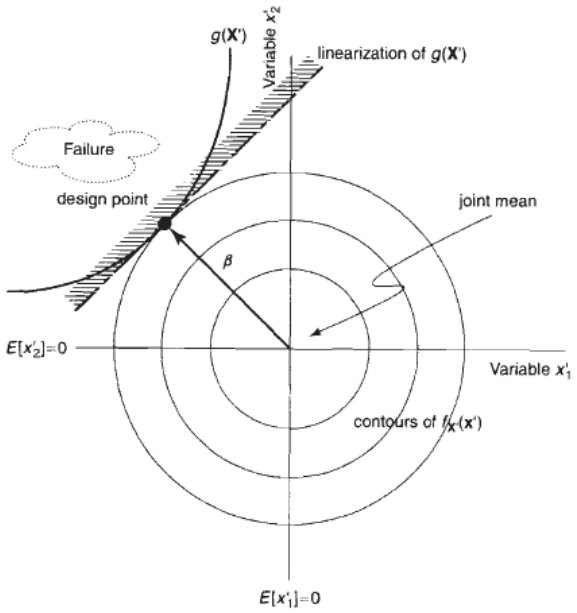


Figure 4.6 Transformed basic variable spaces. (Baecher and Christian 2003)

From the above definition, the basic case of reliability of a system with loading Q (or X_1) and resistance R (or X_2) can be expressed in form of prime variables

$$R' = \frac{R - \mu_R}{\sigma_R} \tag{4.49}$$

$$Q' = \frac{Q - \mu_Q}{\sigma_Q} \tag{4.50}$$

The performance function g for the margin of safety becomes:

$$g = R - Q = \sigma_R R' - \sigma_Q Q' + \mu_R - \mu_Q \tag{4.51}$$

The origin point at which both R and Q equal their values and the distance d between the origin and the line g = 0 is:

$$d = \frac{\mu_R - \mu_Q}{\sqrt{\sigma^2{}_R + \sigma^2{}_Q}} \tag{4.52}$$

The distance d is identical to the definition of the reliability index β. This result suggests that the reliability index can be interpreted geometrically as the distance between the point defined by expected values of the variables and the closest point on the failure criterion.

The following step-by-step procedure, proposed by Ang and Tang 1984, could be used to find the reliability index β (d_{min}).

Step 1:

Assume an initial value for the design point. It is common to start with the mean values of the basic random variables. The design point in the reduced coordinates should then be computed as

$$x_i{}^{*\prime} = \frac{x^*{}_i - \mu_{X_i}}{\sigma_{X_i}} \tag{4.53}$$

Where: μ_{X_i} = mean value of the basic random variable X_i, σ_{X_i} = standard deviation of the basic random variable X_i. The notations x^* and x'^* are used to denote the design point in the regular coordinates and in the reduced coordinate system, respectively.

Step 2:

If the distribution of basic random variables is non-normal, approximate this distribution with an equivalent normal distribution at the design point, having the same tail area and ordinate of the density function with equivalent mean,

$$\mu_{X_i}{}^N = x^* - \phi^{-1}(F_{X_i}(x^*))\sigma_{X_i}{}^N \tag{4.54}$$

and equivalent standard deviation

$$\sigma_{X_i}{}^N = \frac{\phi(\Phi^{-1}(F_{X_i}(x^*)))}{f_{X_i}(x^*)} \tag{4.55}$$

Where:

$\mu_{X_i}{}^N$ = mean value of the equivalent normal distribution

$\sigma_{X_i}{}^N$ = standard deviation of the equivalent normal distribution

$F(x^*)$ = original cumulative distribution function (CDF) of Xi evaluated at the design point

$f(x^*)$ = original PDF of Xi evaluated at the design point

$\Phi(\bullet)$ = CDF of the standard normal distribution

$\phi(\bullet)$ = PDF of the standard normal distribution.

Step 3:

Set $x'^* = -\alpha_i^* \beta$, in which the α_i^* are direction cosines. Compute the directional cosines (α_i^*, i = 1, 2,….., n) using

$$\alpha_i^* = \frac{\left(\frac{\partial g}{\partial x'_i}\right)_*}{\sqrt{\sum_{i=1}^{n}\left(\frac{\partial g}{\partial x'_i}\right)_*^2}} \tag{4.56}$$

Where $\left(\frac{\partial g}{\partial x'_i}\right)_* = \left(\frac{\partial g}{\partial x_i}\right) \times \sigma_{X_i}{}^N$

Step 4:

With $\mu_{X_i}{}^N, \sigma_{X_i}{}^N$, α_i^* now known, the following equation is solved for β:

$$g[(\mu^N{}_{X_1} - \alpha*_{X_1}\, \sigma^N{}_{X_1}\beta), ..., (\mu^N{}_{X_n} - \alpha*_{X_n}\, \sigma^N{}_{X_n}\beta)] = 0 \tag{4.57}$$

Step 5:

Use the β obtained from step 4, a new design point is obtained from

$$x_i = \mu^N{}_{X_i} - \alpha*_{X_i}\, \sigma^N{}_{X_i}\beta \tag{4.58}$$

Step 6:

Repeat steps1 to 6 until convergence of β is achieved.

In this study, the limit state function, g, could be expressed by following equation:

$$g = \ln(R) - \ln\left(\sum Q_i\right) = \ln\frac{R}{\sum Q_i} \tag{4.59}$$

If we only consider the dead loads and live loads, the limit state function can be rewritten in terms of bias factors of the load and resistance as follows:

$$g = \ln\frac{\lambda_R R}{\lambda_{QD} Q_D + \lambda_{QL} Q_L} \tag{4.60}$$

$$\phi R = \gamma_{QD} Q_D + \gamma_{QL} Q_L \tag{4.61}$$

Substituting R from Equation (4.36) to Equation (4.35) yields the following limit state function in terms of the random variables λ_R, λ_{QD} and λ_{QL}

$$g = \ln\frac{\lambda_R(\gamma_{QD} Q_D / Q_L + \gamma_{QL})}{\phi(\lambda_{QD} Q_D / Q_L + \lambda_{QL})} \tag{4.62}$$

4.2.5 Monte Carlo Simulation Method

For more complicated limit state functions, the application of the general statistical method for the calculation of the reliability index is either extremely difficult or impossible. Under this circumstance, the Monte Carlo simulation provides the only feasible way to determine the reliability index or the probability of failure.

The Monte Carlo method is a technique by which a random number generator is used to extrapolate CDF values for each random variable. Extrapolation of CDF makes estimating β possible; otherwise, a limited quantity of data would restrict the reliable estimate of β. Once the reliability index,β, is estimated, the probability of failure can be estimated by assuming the distribution of g(x). The steps of the Monte Carlo simulation method are as follows:

Step1: Generate random numbers for each set of variables.
Here there are three variables (resistance, dead load and live load bias factor), so three sets of random variable have to be generated independently for each one. The number of simulations required is found using the following equation:

$$N = \frac{1 - Ptrue}{V_p^2(P_{true})} \tag{4.63}$$

Where, Ptrue is the lowest magnitude of probability that is to be determined using Monte Carlo, and Vp is the desired coefficient of variation of the simulation result. To estimate a probability as low as 10-2 and keep variance under 10 percent, the number of points to be generated in the Monte-Carlo simulation is 9900.

For each normal variable, the sample value x_i= is estimated as:

$$x_{i(random)} = \mu_x(1 + z_i COV_x) \tag{4.64}$$

For each lognormal variable, the sample value $x_{i(random)}$ is estimated as:

$$x_{i(random)} = \exp(\mu_{lnx}+z_i\sigma_{lnx}) \quad (4.65)$$

Where:

$$\sigma_{lnx} = \ln(COV_x^2+1)^{0.5} \quad \mu_{lnx}= \ln(\mu_x)-0.5\sigma^2_{lnx} \quad (4.66)$$

μ_x: the mean of x

COV_x: the covariance of x

μ_{lnx} : the equivalent lognormal mean of x

σ_{lnx}: the equivalent lognormal standard deviation of x

z_i =NORMSINV(RAND())$_i$ is the random standard normal variable generated using the Matlab function.

In the Monte Carlo simulation, the program generated N groups of random numbers. Each group consisted of 3 random numbers z_1, z_2, and z_3 are normally distributed from 0 to 1. The dead load (DL) and live load (LL) bias factor is normal distribution and resistant bias factor is lognormal distribution. The program then calculated random live load LL_{random}, dead load DL_{random}, and resistance R_{random} using the following equations:

$$LL_{random}=LL.\lambda_{LL}.(1+z_1.COV_{LL}) \quad (4.67)$$

$$DL_{random}=DL.\lambda_{DL}.(1+z_2.COV_{DL}) \quad (4.68)$$

$$R_{radom} = \exp(\mu_{lnR}+z_3\sigma_{lnR}) \quad (4.69)$$

where:

$$\sigma_{lnR} = Ln(COV_R^2+1)^{0.5} \quad (4.70)$$

$$\mu_{lnR} = Ln(\mu_R.\frac{LL.\gamma_{LL}+DL.\gamma_{DL}}{\phi}) - 0.5\sigma^2_{lnR} \quad (4.71)$$

Step 2: Define the limit state function.

From each group of random loads and resistance, the safety margin was calculated using equation

$$g = R_{random} - LL_{random} - DL_{random} \tag{4.72}$$

Step 3: Find the number of cases where $g \leq 0$.

In this equation ϕ is a trial resistance factor. LL and DL are the nominal live load and dead load. γ_{LL} , γ_{DL} , λ_{LL} , λ_{DL} , COV_{LL} and COV_{DL} are listed in the Table . The values for μ_R and COV_R are calculated from the measure capacity and nominal capacity. Paikowsky et al. (2004) found out that the calibrated resistance factor is not sensitive to the change of DL/LL. So in this study the DL/ LL ratio of 2.0 was selected. The only unknown variable is the nominal live load LL. In the Monte Carlo simulation, the magnitude of the nominal load would not affect the result so that LL was simply set to one.

The probability of failure is then defined as:

$$P_f = \frac{count(g \leq 0)}{N} \tag{4.73}$$

and reliability index β is estimated as:

$$\beta = \Phi^{-1}(P_f) \tag{4.74}$$

If the calculated reliability index (β) is different from the selected target reliability index (β_T), the trial resistance factor (β) in step 1 should be changed and iteration needs to be done until $|\beta - \beta_T| <$ tolerance. Prior to the Monte Carlo simulation, a target reliability index β_T and a ratio of dead load must be selected. To be consistent with the AASHTO LRFD Specifications, $\beta_T = 3.0$ for a common design and $\beta_T = 2.33$ for a shaft group with five or more drilled shafts were considered.

5. Resistance Factor Calibration for the Data from Difference Locations in NCHRP Report 507

5.1 Introduction

When design depth foundation in specific location, If we use the resistance factor from report 507, it's may be too low since the author of report 507 use all the data from different locations to calibrate the resistance factors for depth foundation. The purpose of this chapter is to investigate the geo-materials dependence of resistance factor from difference locations by separating the data from NCHRP report 507 and calibrating the resistance factor for different locations.

In the NCHRP report 507, Paikowsky collected numerous static load and dynamic load tests for driven piles from different states in US and different locations in the world. 368 dynamic measurements with signal matching analysis (CAPWAP) cases including 240 cases of end of driving (EOD) and 128 cases of beginning of retrike (BOR) were found in report 507 to be usable in this study.

Beside PDA data, 131 concrete piles have soil profile and static load test including 19 cases in cohesive soil, 37 cases in cohesionless soil and 85 cases in mixed soil are also useful for calibration resistance factor for concrete piles using static methods

Two methods, including First Order Second Moment Method (FOSM) and First-Order Reliability Method (FORM), are using to calibrate the resistance factor for driven piles. In data base some places have small data, 1 to 6 pile cases, in order to have enough data to calibrate resistance factor this study only consider for the locations have more than 7 pile cases

5.2 Calibration Resistant Factor for Driven Piles Using CAPWAP Method

5.2.1 Resistance Factor for Different Locations by Using CAPWAP (BOR+EOD) Data

Table 5.1a and 5.1b show the resistance factor calibration by using both FOSM and FORM with reliability index β=2.33 and β=3.0 for driven piles using CAPWAP method with both BOR and EOD data. The detail calibration resistance factor ϕ by

using FORM is in the appendix A (from Fig A-1a to Fig A-13b) and by using FOSM method is in the appendix C (from table C-1 to table C-13). Figure 5.1 and 5.2 show the different resistance factor ϕ for different location with reliability index β=2.33 and β=3.0. The resistance factor ϕ varies with different locations. S Carolina has the lowest resistance factor whereas Oakland, CA has the highest resistance factor

Table 5.1a Resistance Factors for Driven Piles using CAPWAP (BOR+EOD) for Different Locations

Location		Total	Florida	Winconsin	Lousiana	Massachusetts	S Carolina
Number of Cases-N		368	107	27	22	17	16
Mean-λ		1.426	1.324	1.353	2.743	1.515	1.411
Standard deviation-σ		0.912	0.571	0.742	2.502	0.758	0.930
COV		0.639	0.431	0.548	0.912	0.500	0.659
Φ (FOSM)	β=2.33	0.386	0.564	0.446	0.425	0.555	0.306
	β=3.0	0.254	0.412	0.307	0.247	0.392	0.199
Φ (FORM)	β=2.33	0.406	0.611	0.478	0.443	0.595	0.388
	β=3.0	0.277	0.467	0.340	0.266	0.433	0.261

Table 5.1b Resistance Factors for Driven Piles using CAPWAP (BOR+EOD) for Different Locations

Location		Ortanrio	Alabama	Pennsyvania	Oakland, CA	Nebraska	Canada	Oklahoma
Number of Cases-N		15	14	12	13	9	8	7
Mean-λ		1.160	1.397	0.881	1.843	1.237	0.967	1.529
Standard deviation-σ		0.294	0.383	0.201	0.671	0.423	0.209	0.635
COV		0.254	0.274	0.228	0.364	0.342	0.216	0.415
Φ (FOSM)	β=2.33	0.715	0.828	0.570	0.908	0.638	0.640	0.675
	β=3.0	0.573	0.656	0.462	0.688	0.489	0.521	0.498
Φ (FORM)	β=2.33	0.809	0.931	0.652	0.996	0.704	0.736	0.733
	β=3.0	0.779	0.675	0.767	0.779	0.558	0.626	0.558

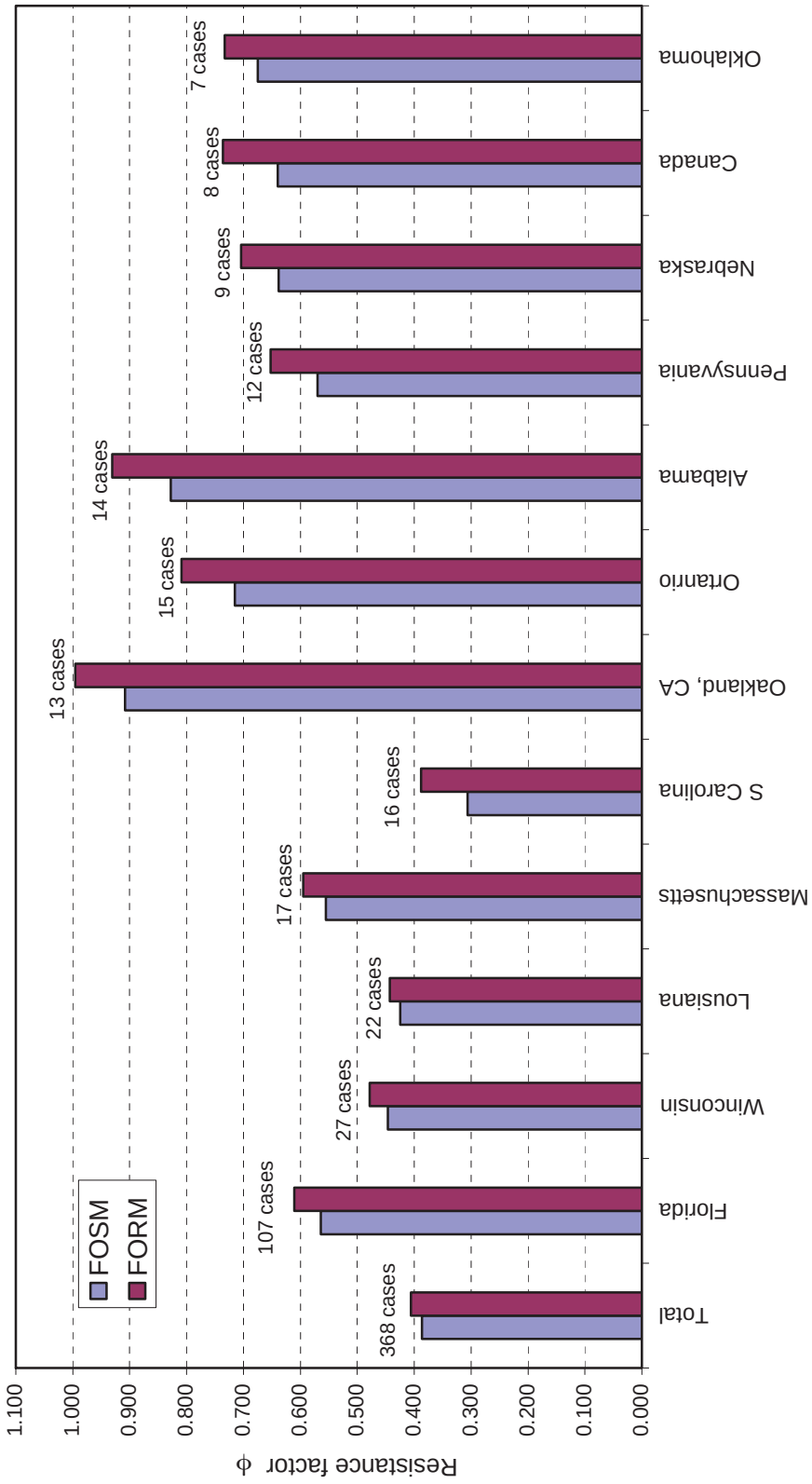


Figure 5.1 Resistance Factors ϕ for Driven Piles Using CAPWAP (EOD+BOR) with β =2.33

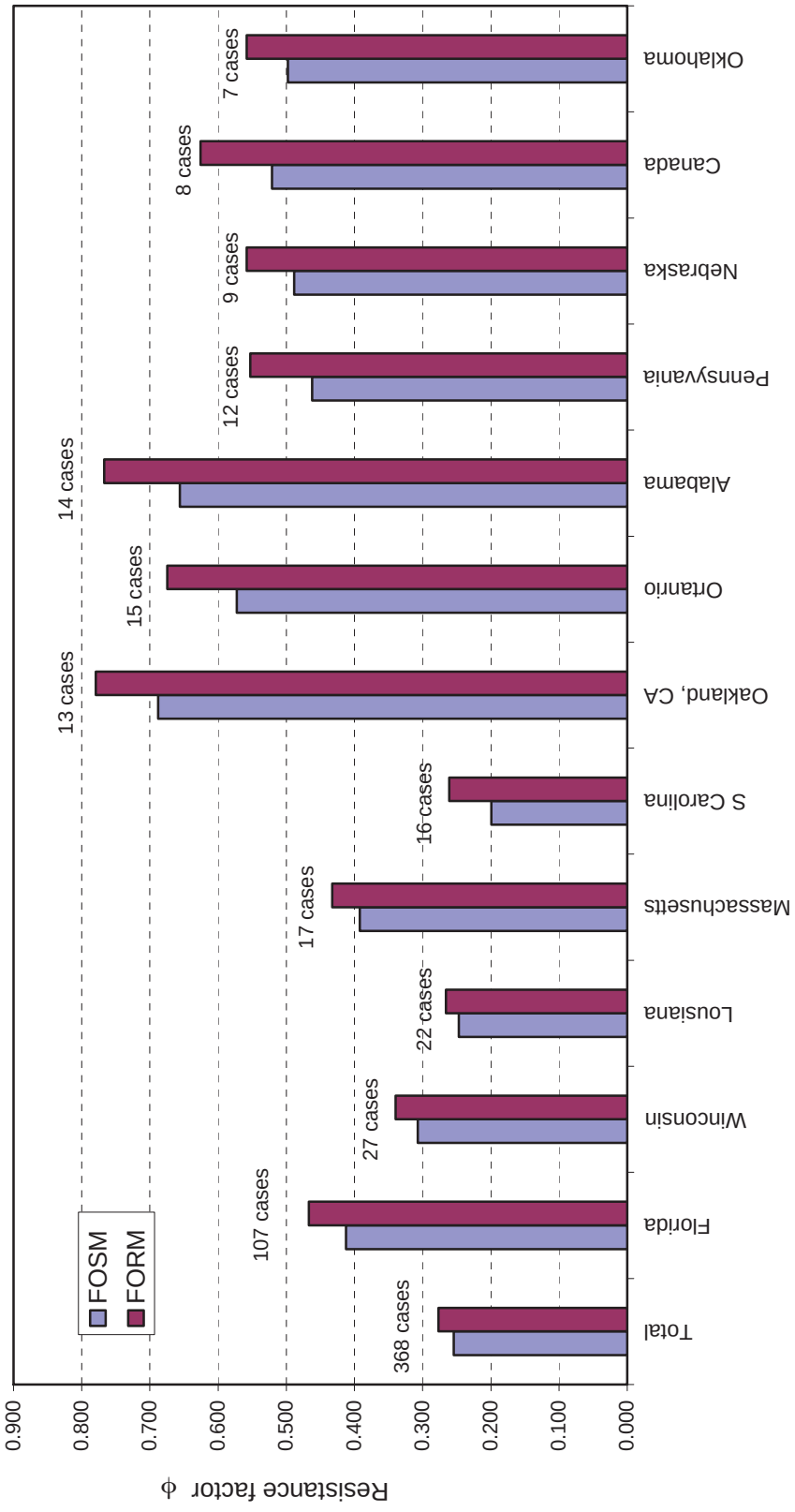


Figure 5.2 Resistance Factors ϕ for Driven Piles Using CAPWAP (EOD+BOR) with β =3.0

5.2.2 Resistance Factor for Different Locations by Using CAPWAP (BOR) Data

Table 5.2 shows the resistance factor calibration by using both FOSM and FORM with reliability index β=2.33 and β=3.0 for driven piles using CAPWAP with BOR data. The detail calibration resistance factor ϕ by using FORM is in the appendix A (from Fig A-14a to Fig A-20b) and by using FOSM method is in the appendix C (from table C-14 to table C-19). Figure 5.3 and 5.4 show the different resistance factor ϕ for different locations with reliability index β=2.33 and β=3.0. The resistance factor ϕ varies with different locations. Wisconsin has the lowest resistance factor whereas Louisiana and Ontario have the highest resistance factor.

Table 5.2 Resistance Factors for Driven Piles using CAPWAP (BOR) for Different Locations

Location		Total	Florida	Wisconsin	Louisiana	Caronila	Alabama	Ontario
Number of Cases-N		240	85	18	15	13	9	8
Mean-λ		1.220	1.243	0.964	1.698	1.158	1.230	1.118
Standard deviation-σ		0.454	0.475	0.286	0.592	0.285	0.351	0.180
COV		0.372	0.382	0.296	0.349	0.246	0.285	0.161
Φ (FOSM)	β=2.33	0.590	0.589	0.547	0.863	0.703	0.713	0.809
	β=3.0	0.445	0.442	0.429	0.659	0.565	0.562	0.675
Φ (FORM)	β=2.33	0.652	0.645	0.610	0.950	0.824	0.802	0.953
	β=3.0	0.505	0.498	0.497	0.750	0.688	0.655	0.836

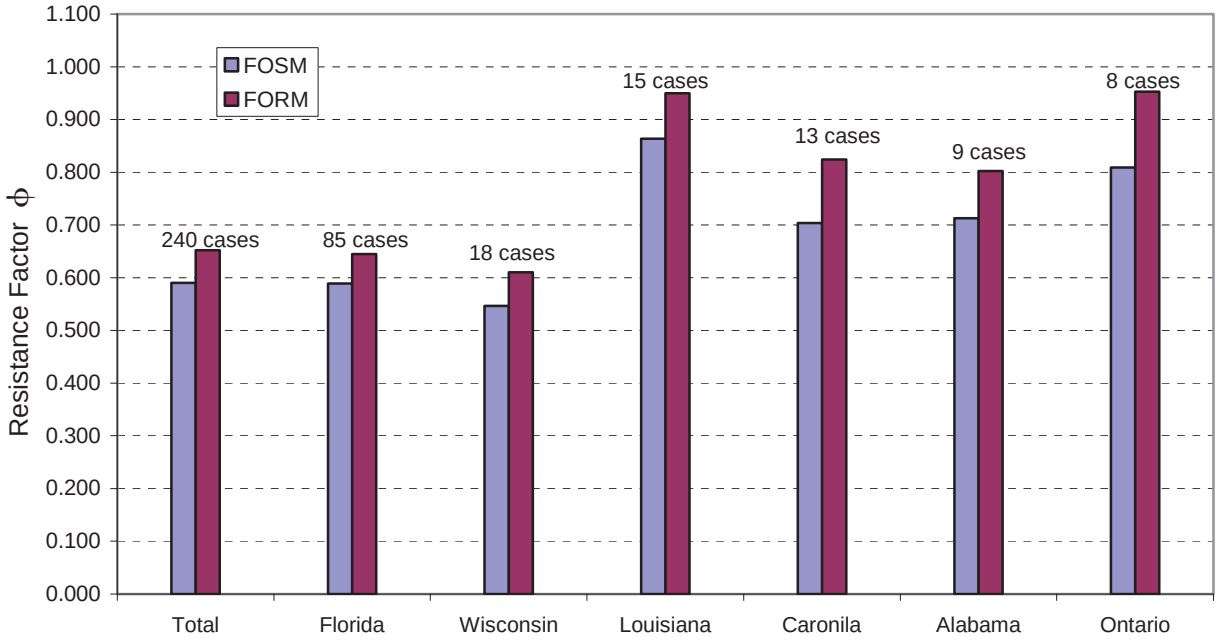


Figure 5.3 Resistance Factors ϕ for Driven Piles Using CAPWAP (BOR) with β =2.33

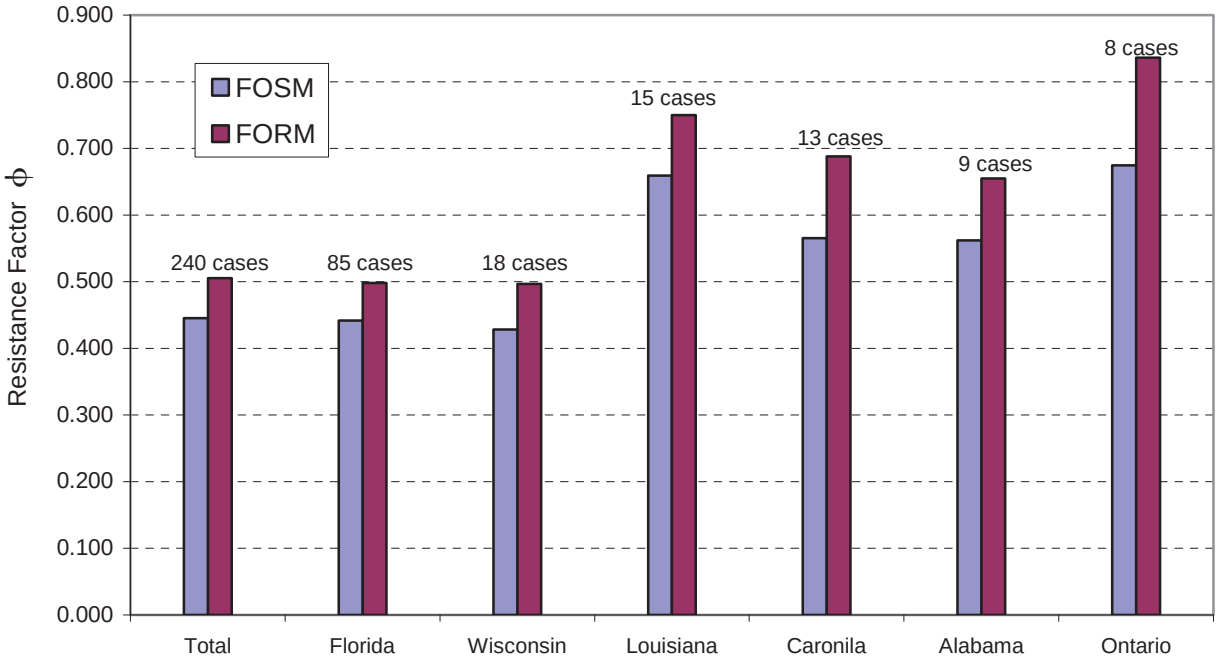


Figure 5.4 Resistance Factors ϕ for Driven Piles Using CAPWAP (BOR) with β =3.0

5.2.3 Resistance Factor for Different Locations by Using CAPWAP (EOD) Data

Table 5.3 shows the resistance factor calibration by using both FOSM and FORM with reliability index β=2.33 and β=3.0 for driven piles using CAPWAP with EOD data. The detail calibration resistance factor ϕ by using FORM is in the appendix A (from Fig A-21a to Fig A-27b) and by using FOSM method is in the appendix C (from table C-20 to table C-25). Figure 5.5 and 5.6 show the different resistance factor ϕ for different location with reliability index β=2.33 and β=3.0. The resistance factor ϕ varies with locations. Pittsburgh, PA has the lowest resistance factor whereas Oakland, CA and Wisconsin have the highest resistance factor. If including all the EOD data from different location, the resistance factor will be the lowest one

Table 5.3 Resistance Factors for Driven Piles (EOD) using CAPWAP for Different Locations

Location		Total	Florida	Massachusetts	Pittsburgh, PA	Oakland, CA	Wisconsin	Ontario
Number of Cases-N		128	18	11	9	8	8	7
Mean-λ		1.789	1.503	1.728	0.820	2.191	2.294	1.208
Standard deviation-σ		1.337	0.650	0.904	0.192	0.629	0.637	0.399
COV		0.748	0.433	0.523	0.235	0.287	0.278	0.330
Φ (FOSM)	β=2.33	0.385	0.638	0.602	0.524	1.265	1.349	0.639
	β=3.0	0.241	0.467	0.419	0.423	0.997	1.068	0.493
Φ (FORM)	β=2.33	0.456	0.654	0.644	0.596	1.416	1.515	0.706
	β=3.0	0.265	0.498	0.462	0.503	1.154	1.243	0.565

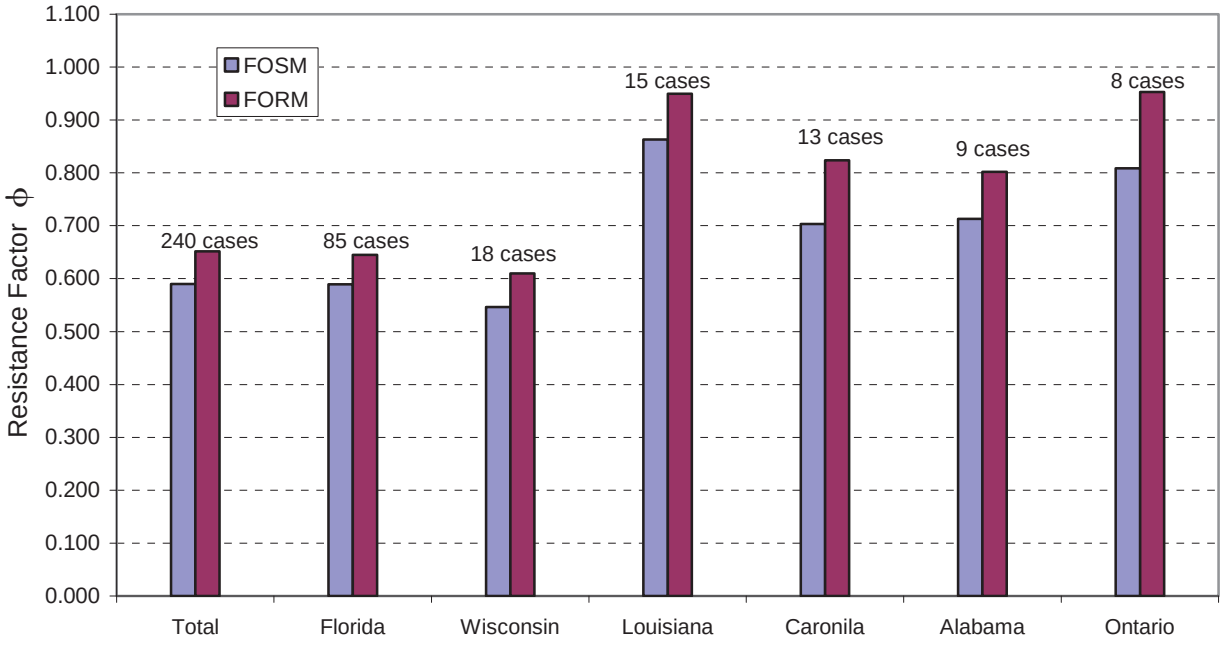


Figure 5.5 Resistance Factors ϕ for Driven Piles Using CAPWAP (EOD) with β =2.33

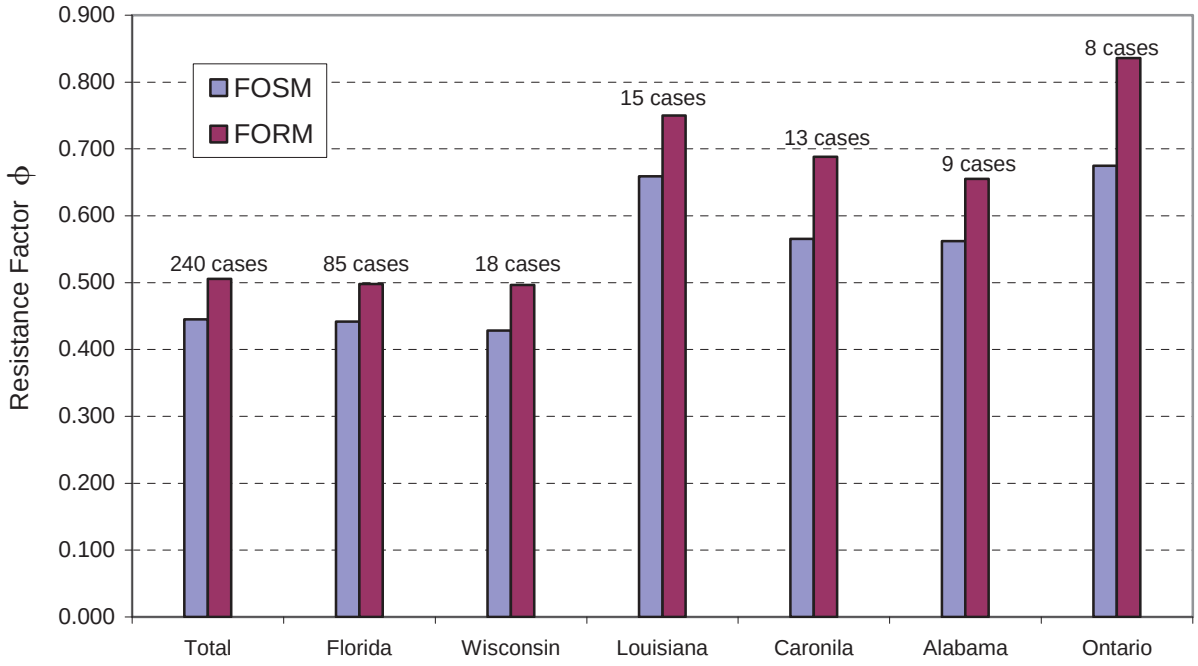


Figure 5.6 Resistance Factors ϕ for Driven Piles Using CAPWAP (EOD) with β =3.0

5.3 Calibration Resistant Factor for Driven Piles Using Static Analysis

5.3.1 Resistance Factor for Concrete Piles in Cohesionless from Different Locations

The resistance factor calibration from all 37 data for concrete in cohesionless soil by using different static method, Nordlund, beta, Meyerhof, Schmertmann SPT are showed in table 5.4a and for the Florida data only is showed in table 5.4b.

Table 5.4a Resistance Factors for Concrete Piles in Cohesionless Soil

Method		Nordlund	β	Meyerhof	Schmertmann SPT
Number of Cases-N		37	37	37	37
Mean-λ		1.06	1.17	0.64	1.25
Standard deviation-σ		0.55	0.56	0.42	0.62
COV		0.52	0.48	0.65	0.49
Φ (FOSM)	β=2.33	0.37	0.45	0.17	0.46
	β=3.0	0.26	0.32	0.11	0.33
Φ (FORM)	β=2.33	0.4	0.483	0.183	0.5
	β=3.0	0.289	0.356	0.125	0.364

Table 5.4b Resistance Factors for Concrete Piles in Cohesionless Soil for Florida Data Only

Method		Nordlund	β	Meyerhof	SchmertmannSPT
Number of Cases-N		27	27	27	27
Mean-λ		1.113	1.216	0.591	1.191
Standard deviation-σ		0.525	0.545	0.358	0.508
COV		0.471	0.448	0.606	0.427
Φ (FOSM)	β=2.33	0.43	0.50	0.17	0.51
	β=3.0	0.31	0.36	0.12	0.38
Φ (FORM)	β=2.33	0.469	0.54	0.183	0.557
	β=3.0	0.347	0.403	0.125	0.42

5.3.2 Resistance Factor for Concrete Piles in Cohesive for Different Locations

The resistance factor calibration from all 19 data for concrete in cohesive soil by using different static method, α-API revised, α-Tomlinson, λ are showed in table 5.5a and for the Louisiana data only is showed in table 5.5b.

Table 5.5a Resistance Factors for Concrete Piles in Cohesive Soil

Method		α-API revised	α-Tomlinson	λ
Number of Cases-N		19	19	19
Mean-λ		0.89	0.94	0.79
Standard deviation-σ		0.31	0.50	0.25
COV		0.35	0.54	0.32
Φ (FOSM)	β=2.33	0.45	0.32	0.30
	β=3.0	0.34	0.22	0.21
Φ (FORM)	β=2.33	0.498	0.34	0.342
	β=3.0	0.393	0.243	0.243

Table 5.5b Resistance Factors for Concrete Piles in Cohesive Soil for Louisiana Data Only

Method		α-API revised	α-Tomlinson	λ
Number of Cases-N		12	12	12
Mean-λ		0.818	0.718	0.833
Standard deviation-σ		0.236	0.322	0.201
COV		0.289	0.449	0.241
Φ (FOSM)	β=2.33	0.47	0.29	0.53
	β=3.0	0.37	0.21	0.42
Φ (FORM)	β=2.33	0.527	0.319	0.598
	β=3.0	0.431	0.241	0.50

5.3.3 Resistance Factor for Concrete Piles in Mixed soil for Different Locations

The resistance factor calibration from all 85 data for concrete in mixed soil by using different static method are showed in table 5.6a, from Florida and Louisiana data only is showed in table 5.6b and 5.6c

Table 5.6a Resistance Factors for Concrete Piles in Mixed Soil

Method		Tomlinson Nordlund Thurman	API Nordlund Thurman	β Thurman	Schmertmann	
					SPT	CPT
Number of Cases-N		34	85	85	74	32
Mean-λ		1.00	0.88	0.93	1.97	0.90
Standard deviation-σ		0.52	0.47	0.55	1.21	0.35
COV		0.52	0.54	0.59	0.61	0.39
Φ (FOSM)	β=2.33	0.35	0.30	0.28	0.57	0.42
	β=3.0	0.25	0.21	0.19	0.38	0.31
Φ (FORM)	β=2.33	0.381	0.348	0.3	0.6	0.45
	β=3.0	0.275	0.228	0.208	0.41	0.354

Table 5.6b Resistance Factors for Concrete Piles in Mixed Soil for Florida Data Only

Method		α-Tomlinson Nordlund Thurman	α-API Nordlund Thurman	β Thurman	Schmertmann
					SPT
Number of Cases-N		12	42	42	55
Mean-λ		0.95	0.97	1.11	1.87
Standard deviation-σ		0.57	0.52	0.61	1.10
COV		0.60	0.54	0.54	0.59
Φ (FOSM)	β=2.33	0.28	0.33	0.37	0.56
	β=3.0	0.19	0.23	0.26	0.38
Φ (FORM)	β=2.33	0.296	0.352	0.395	0.595
	β=3.0	0.201	0.253	0.282	0.41

Table 5.6c Resistance Factors for Concrete Piles in Mixed Soil for Louisiana Data Only

Method		α-Tomlinson Nordlund Thurman	α-API Nordlund Thurman	β Thurman	Schmertmann CPT
Number of Cases-N		16	31	31	25
Mean-λ		1.09	0.68	0.64	0.87
Standard deviation-σ		0.52	0.23	0.16	0.33
COV		0.48	0.34	0.26	0.38
Φ (FOSM)	β=2.33	0.42	0.35	0.39	0.41
	β=3.0	0.30	0.27	0.31	0.31
Φ (FORM)	β=2.33	0.45	0.39	0.446	0.455
	β=3.0	0.329	0.309	0.371	0.354

6. Data Collection from Vietnam

6.1 Introduction

Vietnam is the developing country in Southeast Asia. Now in Vietnam, they start to build many highways and highrise building to develop the country. When design the deep foundations for bridge and building, they still use the allowable stress design (ASD), but most of the highways and buildings from the foreigner investors, who require using the load resistant factor design (LRFD). For this reason, this research collected soil profile and static and dynamic load tests for driven pile and drilled shafts in North, Central and South of Vietnam to calibrate the first LRFD for deep foundation in Vietnam In this study, Vietnam is divided into three regions: North, South and Central, as shown in Figure 6.1



Figure 6.1 Vietnamese Map

Each region is divided into mountain, alluvia plain and coastal. Most driven pile and drilled shaft load test data are from cities in the Red River delta in the North, such as Hanoi, Hai Phong and Hai Duong, in the Mekong River Delta in the South, such as Sai Gon, Vung Tau, and along the Central coast, such as Vinh, Hue, Danang. Most highways, high rises are located in these areas. 275 static load tests for driven piles and 92 static load tests for drilled shafts have been collected from Vietnam. Each set of pile test data also comes with detailed soil profile. Tables E-1 and E-2 in Appendix E show the data collected.

6.2 General description of Vietnam geology

6.2.1 North Vietnam

This region is characterized by large formations of Red River depositional units of clay, sand, very soft clay, soft sandy clay and clayey sand, the entire region has the soft soil. Table 6.1 provides the general stratification of the sub-soils North Vietnam, and Table 6.2 gives the average properties of each soil type.

Figure 6.2 shows the six regions including A, B, C, D, E, F which have different depth of the gravel layer in Hanoi. The depth gravel layer is very important factor to determine the depth of drilled shaft.

- The depth of gravel in region A: $h \leq 30$m
- The depth of gravel in region B: $h = 30$-35m
- The depth of gravel in region C: $h = 35$-40m
- The depth of gravel in region D: $h = 40$-45m
- The depth of gravel in region E: $h = 45$-50m
- The depth of gravel in region F: $h > 50$m

Table 6.1 General soil profile in North Vietnam

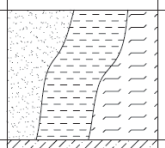
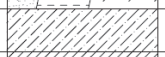
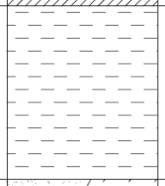
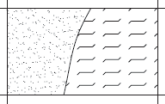
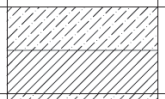
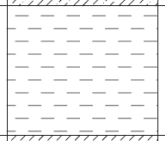
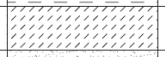
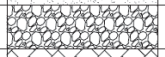
No		Thickness (m)		Soil Layer
1		0.3-6	1a	Very Fine Sand
			1b	Muddy Sandy Clay
			1c	Clayey Sand
2		0.3-8	2	Sandy Clay
3		0.3-6	3	Clayey
4		10-19	4a1	Muddy Peat
			4a2	Muddy Clay
			4b	Muddy Sandy Clay
			4c	Muddy Clayey Sand
5		10-12	5a	Fine Sand
			5b	Clayey Sand
		10-15	5c	Coble
6		2-18.5	6a	Clay (multi color)
			6b	Clay (gray)
7		0.6-4.5	7	Sandy Clay
8		1-10	8a	Muddy Clay
			8b	Muddy Sandy Clay
			8c	Muddy Clayey Sand
9		0.5-0.8	9	Clayey Sand
10		0.5-40	10	Medium to Coarse Sand
11		10-30	11	Gravel, Coble
12			12	Bed rock

Table 6.2 Mean Values Properties of Each Soil Type North Vietnam

Layer		<0.005mm (%)	W (%)	γ_{wet} (g/cm^3)	γ_{solid} (g/cm^3)	γ_{dry} (g/cm^3)	e	S (%)	LL	PI	ϕ degree	C (kg/cm^3)
1a	Very Fine Sand	-	30	1.82	2.7	1.4	0.93	87.5			27	0.08
1b	Muddy Sandy Clay	17	44	1.7	2.69	1.18	1.26	92.5	37	13	14	0.01
1c	Clayey Sand	6	28	1.82	2.67	1.42	0.88	85.5	27	6	19	0.07
2	Sandy Clay	18	29	1.88	2.71	1.46	0.85	91.5	36	14	15	0.24
3	Clay	40	33	1.85	2.71	1.39	0.95	94.3	44	21	12	0.38
4a1	Muddy Peat	38	76	1.49	2.69	0.85	2.07	95.6	60	23	6	0.14
4a2	Muddy Clay	45	59	1.65	2.7	1.04	1.6	99.5	51	25	8	0.11
4b	Muddy Sandy Clay	23	42	1.73	2.69	1.22	1.2	93.8	37	13	16	0.05
4c	Muddy Clayey Sand	7	36	1.78	2.69	1.31	1.05	92.2	32	6	19	0.03
5a	Fine Sand	-	26	1.81	2.67	1.46	0.83	84			28	0.04
5b	Clayey Sand	6	29	1.85	2.68	1.14	0.87	85.8	27	7	20	0.08
5c	Coble	-	-	-	-	-	-	-	-	-	-	-
6a	Clay (multi color)	25	32	1.86	2.72	1.41	0.93	93.5	38	16	13	0.19
6b	Clay (gray)	44	42	1.87	2.72	1.32	1	100	46	21	10	0.22
7	Sandy Clay	21	28	1.85	2.7	1.48	0.83	91.5	32	13	15	0.16
8a	Muddy Clay	42	62	1.58	2.63	0.97	1.71	94.8	55	24	11	0.16
8b	Muddy Sandy Clay	22	43	1.74	2.69	1.22	1.21	95.7	37	12	17	0.09
8c	Muddy Clayey Sand	8	39	1.84	2.7	1.32	1.04	100	32	5	25	0.05
9	Clayey Sand	9	29	1.85	2.67	1.43	0.86	90	28	5	27	0.1
10	Medium to Coarse Sand	-	26	1.87	2.67	1.19	0.8	86.6			33	0.02

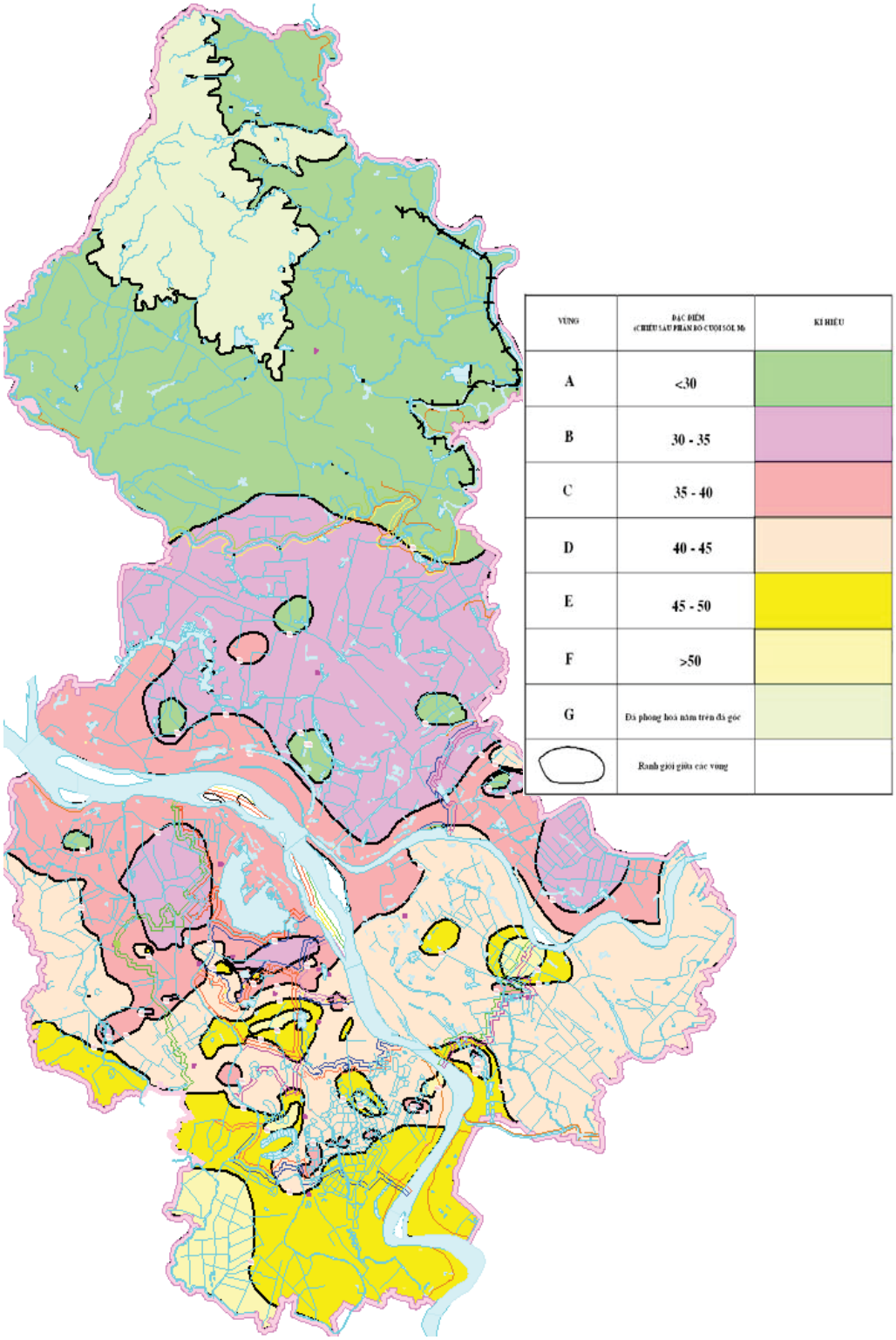


Figure 6.2 the depth of bearing layer (gravel) in Hanoi

6.2.2 South Vietnam

This region is characterized by low relief and large formations of Mekong River depositional units of soft soil, including: clay, sand, very soft clay, and soft clayey sand clay in the upper layer, coarse sand to gravel in the lower layer underlain by moderately to highly weathered bedrock. The thickness of soft soil usually ranges from 3m to 30 m, however, in some areas it can be as thick as 300m. The soft soil stratification in this region starts with 0.5 to 1.5m of top soil, below which are inorganic clay, organic clay, very soft clay, soft clayey sand, and the lacustrine clay with interbeded layers of thin sand and clay. The thickness of organic layers range from 3m to 4m in Long An, from 9 to 10m in Thach Anh, Hau Giang and from18-20m in Long Phu, Hau Giang. This layer has very high moisture content, 40% to 70% in clay with 2% to 8% organic materials. Table 6.3a and 6.3b summarize the properties of this layer. The nonorganic clay usually 3-4m below the surface in Long An, 9-10m in Thach Anh, Hau Giang, 15-16 m in Vinh Qui, Tan Long, Hau Giang, 25-26m in My Thanh, Hau Giang, and much deeper near the coastal margin. Table 6.4a and 6.4b summarize the properties of this layer. Between organic clay and inorganic clay is a sandy clay with thickness about 3 to 5m. The water table is at 0.5m to 2m below the ground surface.

Table 6.3a Properties of Organic Clay Layer in South Vietnam

Moisture content – ω	50-100% (some area ω >100%)
Liquid limit – ω_L	50-100%
Plastic Limit – ω_P	20-70%
Void Ratio – e	1.2-3.0 (some area e>3.0)
Unit Weight – γ_w	1.35-1.65 g/cm^3
Dry Unit Weight – γ_c	0.64-0.95 g/cm^3

Table 6.3 b Friction Angle and Cohesion of Organic Clay Layer in South Vietnam

Void ration – e	1.2 – 2.0	1.2 – 2.0	1.4 – 3.0	1.4 – 4.0	1.4 – 4.0
Mean of ϕ	10°	9°	8°	7°	5°
STD of ϕ	$1^o45'$	$1^o30'$	$1^o12'$	$1^o15'$	$1^o30'$
Mean of C (Kg/cm^2)	0.12	0.10	0.08	0.06	0.05
STD of C (Kg/cm^2)	0.02	0.03	0.02	0.02	0.02

Table 6.4a Properties of Non-Organic Clay Layer in South Vietnam

Moisture content – ω	22-55% (some area ω >100%)
Liquid limit – ω_L	40-65%
Plastic Limit – ω_P	20-30%
Void Ratio – e	0.7-1.5 (some area e>3.0)
Unit Weight – γ_w	1.65-1.95 g/cm^3
Dry Unit Weight – γ_c	1.05-1.55 g/cm^3

Table 6.4 b Friction Angle and Cohesion of Inorganic Clay Layer in South Vietnam

Void ratio e	0.75 – 1.0	0.85 – 1.2	0.85 – 1.2	1.1 – 1.4	1.2 – 1.5
Mean of ϕ	17°	13°	11°	$9^o30'$	$8^o30'$
STD of ϕ	$2^o12'$	$1^o45'$	3°	$1^o12'$	$9^o45'$
Mean of C (Kg/cm^2)	0.28	0.22	0.18	0.15	0.10
STD of C (Kg/cm^2)	0.03	0.04	0.04	0.04	0.03

6.2.3 Central Vietnam

This region is characterized by low relief and large formations of shallow marine depositional units of soft soil, including fine sand, sandy clay and clay in the upper layer, coarse sand to gravel in the lower layer underlain by moderately to highly weathered bedrock. The thickness of upper layer ranges from 15m to 40m with SPT blow count, N, from 2 to 15 and the moisture content is very high from 35 to 70%. The lower layer has

higher SPT blow count from 20 to 45 or higher with the thickness of 4m to 10m. This layer is good for resting the tip of driven piles and drilled shafts.

6.3 Static Load Tests and Soil Profile from a site in Vietnam

The name of this project is Red River Shipyard and the location of project in Hoang Mai-Hanoi. Figures 6.1, 6.2a, 6.2b, 6.2c, 6.2d show the site plan and four boring logs for this project. Tables 6.5, 6.6 and 6.7 show the summary of SPT and the properties of each soil layer. Figures 6.3a, 6.3b, 6.3c, 6.3d and 6.3e show static load test data for 5 (350mm x350mm) prestressed concrete piles. As can be seen, all load tests were carried out to a vertical load twice the design capacities, instead of failure. Thus, Chin's method was used to extend the load settlement curve in an attempt to estimate ultimate capacities.

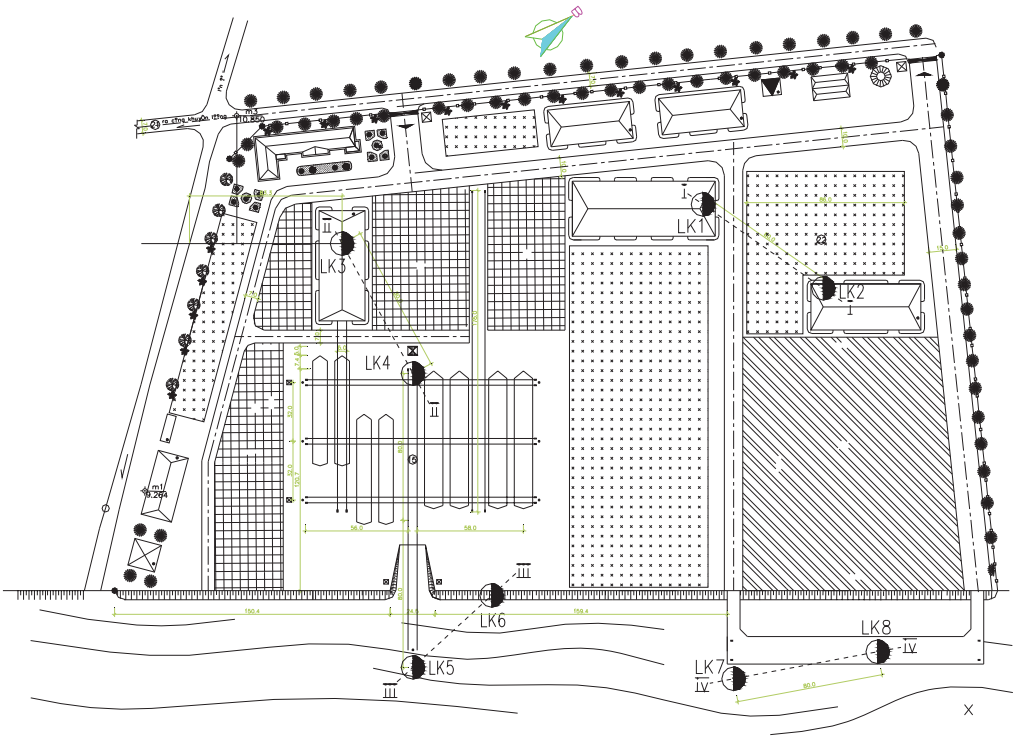


Figure 6.2 Red River Shipyard Project Site Plan

Table 6.5 Summary SPT value of each Layer

No	Layer	Soil Type	Average Thickness of Layer (m)	NSPT			Number of SPT tests
				Max	Mean	Min	
1	Layer 1a		0.83	-	-	-	-
2	Layer 1b		0.38	-	-	-	-
3	Layer 2	CL	2.13	4	3	3	6
4	Layer 3	CL	7.50	7	5	5	6
5	Layer 4	SC	4.86	9	7	6	17
6	Layer 5	CL	4.50	5	3	3	14
7	Layer 6	SC	7.48	9	7	5	24
8	Layer 7	SC	10.49	29	25	11	40
9	Layer 8	SP	2.62	28	22	20	10
10	Layer 9	CL	2.80	8	7	6	4
11	Layer 10	CL	4.30	14	11	11	9
12	Layer 11	SC	-	42	34	30	24

Table 6.6 Summary of Soil Properties of Clay Layer

Properties	Unit	Layer				
		Layer 2	Layer 3	Layer 5	Layer 9	Layer 10
5.0-2.0 (mm)	%					3.2
2.0-1.0 (mm)	%	0.3		1.1		1.9
1.0-0.5 (mm)	%	1.3	1.0	2.8	1.6	2.1
0.5-0.25 (mm)	%	4.9	4.4	5.9	3.4	4.1
0.25-0.1 (mm)	%	21.2	8.2	22.7	7.4	6.8
0.1-0.05 (mm)	%	22.7	13.1	21.5	16.5	13.0
0.05-0.01(mm)	%	25.2	34.6	23.4	26.2	27.3
0.01-0.005(mm)	%	15.6	23.8	15.0	21.0	21.3
<0.005 (mm)	%	9.2	15.3	8.9	24.6	25.3
W	%	40.8	28.4	29.0	29.7	26.4
LL	%	43.9	33.4	30.8	36.1	35.2
PL	%	28.1	19.61	20.5	20.8	19.8
PI	%	15.8	13.8	10.2	15.3	15.4
γ_{wet}	g/cm^3	1.72	1.81	1.72	1.93	1.94

Table 6.6 (cont.)

γ_{dry}	g/cm^3	1.22	1.40	1.33	1.49	1.53
γ_{solid}	g/cm^3	2.67	2.69	2.65	2.73	2.72
n	%	54.3	47.8	49.8	45.4	43.7
ε		1.187	0.915	0.994	0.830	0.777
S	%	91.8	83.5	77.5	97.6	92.4
C	kG/cm^2	0.045	0.196	0.083	0.139	0.259
φ		$6^0$55’	$11^0$57’	$9^0$10’	$10^0$52’	$14^0$12’
$\tau_{0.25}$	kG/cm^2	0.077	0.236	0.134	0.077	
$\tau_{0.5}$	kG/cm^2	0.103	0.319	0.167	0.245	0.391
$\tau_{0.75}$	kG/cm^2	0.137		0.232		
$\tau_{1.0}$	kG/cm^2		0.399		0.298	0.506
$\tau_{2.0}$	kG/cm^2				0.710	0.768

Table 6.7 Summary of Soil Properties of Sand Layer

Properties	Unit	Layer				
		Layer 4	Layer 6	Layer 7	Layer 8	Layer 11
20.0-10.0 (mm)	%				16.8	
10.0-5.0 (mm)	%				31.7	
5.0-2.0 (mm)	%				13.6	
2.0-1.0 (mm)	%			1.1	4.4	
1.0-0.5 (mm)	%		2.4	2.8	5.2	0.5
0.5-0.25 (mm)	%	2.9	4.4	5.0	4.2	2.3
0.25-0.1 (mm)	%	11.8	21.0	57.0	4.1	18.7
0.1-0.05 (mm)	%	80.3	69.7	33.6	21.3	74.3
<0.05 (mm)	%	5.3	4.6	3.4	2.2	4.9
0.01-0.005 (mm)	%					
<0.005 (mm)	%					
γ_{wet}	g/cm^3	1.23	1.23	1.33		1.26
γ_{dry}	g/cm^3	1.47	1.46	1.48		1.46
γ_{solid}	g/cm^3	2.67	2.67	2.68	2.68	2.70
n	%					
ε_{max}		1.176	1.165	1.010		1.126
ε_{min}		0.818	0.825	0.811		0.825

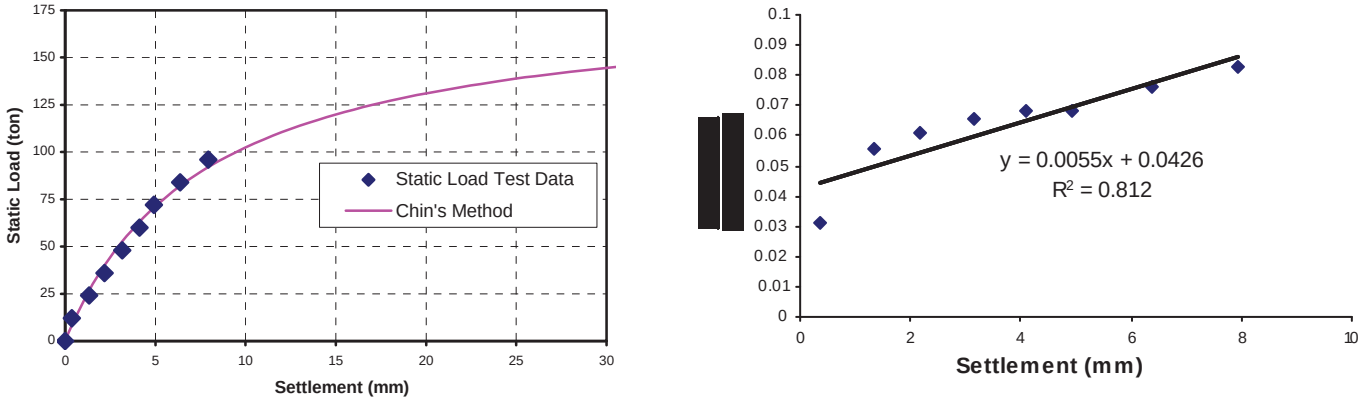


Figure 6.4a Static Load Test Data and Chin's Method for A5-2 (350x350) Concrete Pile

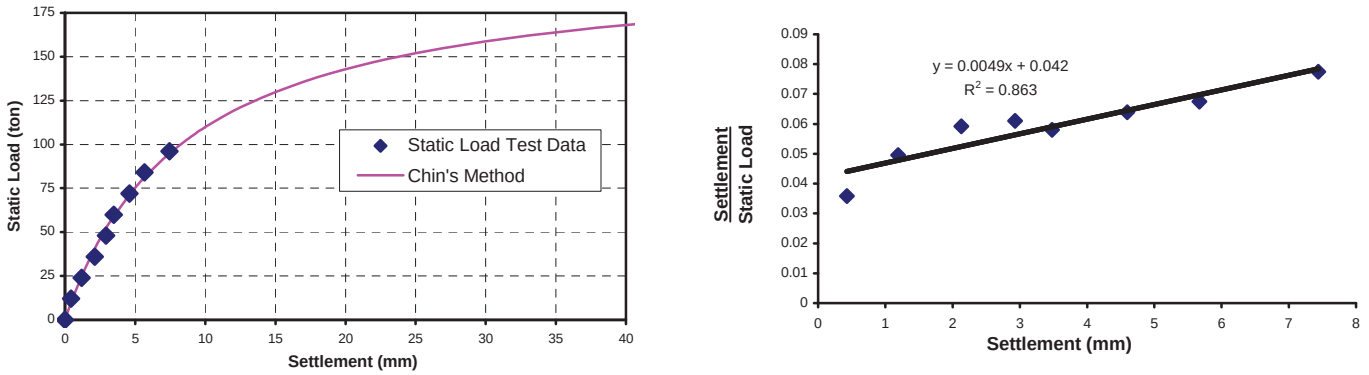


Figure 6.4b Static Load Test Data and Chin's Method for A1-5 (350x350) Concrete Pile

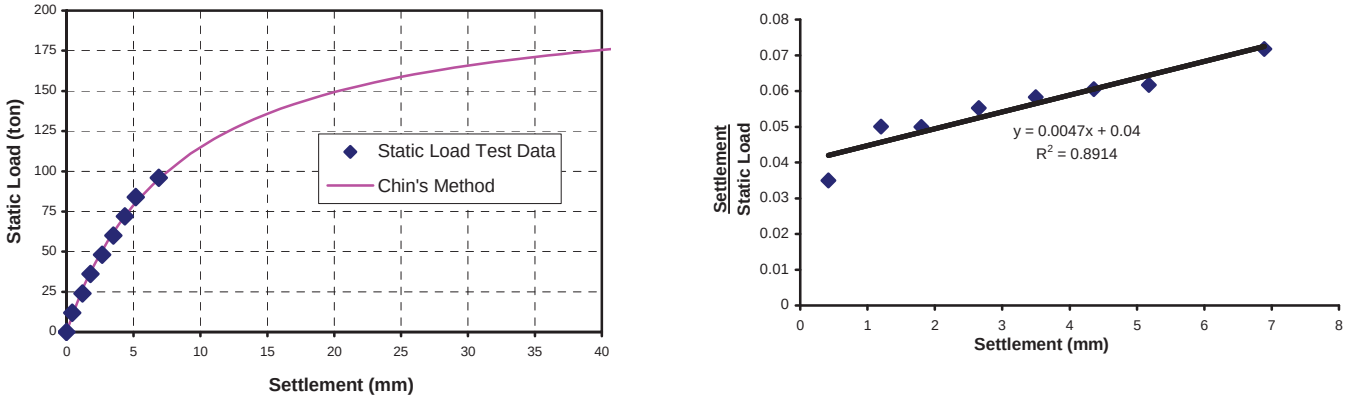
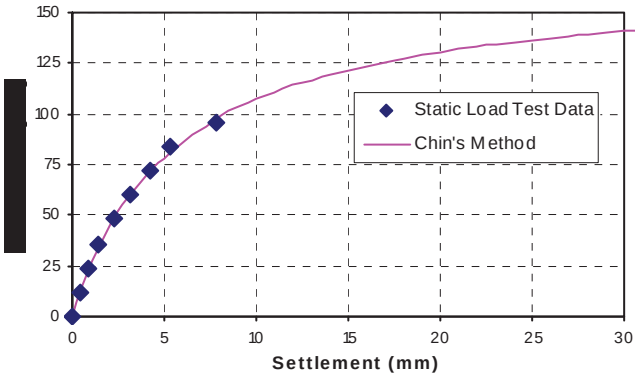


Figure 6.4c Static Load Test Data and Chin's Method for B1-2 (350x350) Concrete Pile



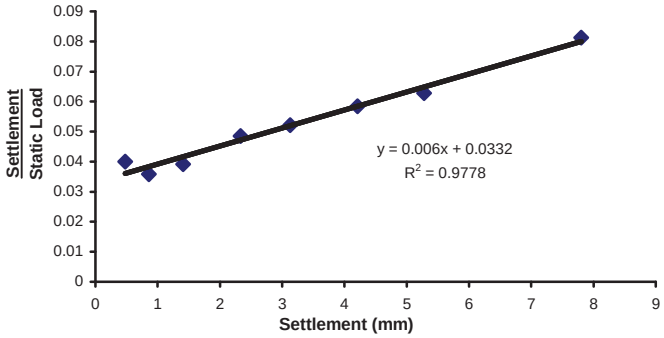
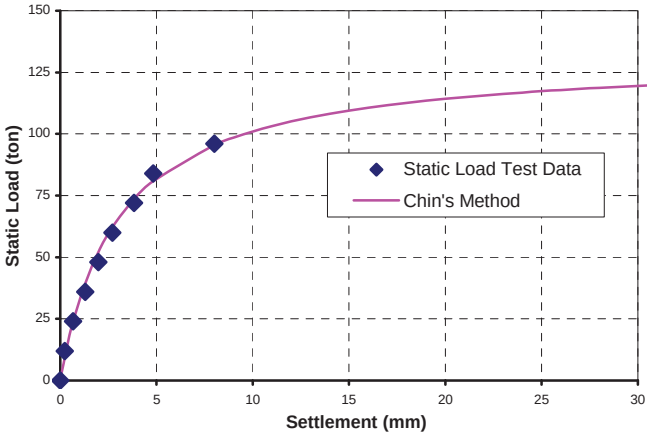


Figure 6.4d Static Load Test Data and Chin's Method for B5-2 (350x350) Concrete Pile



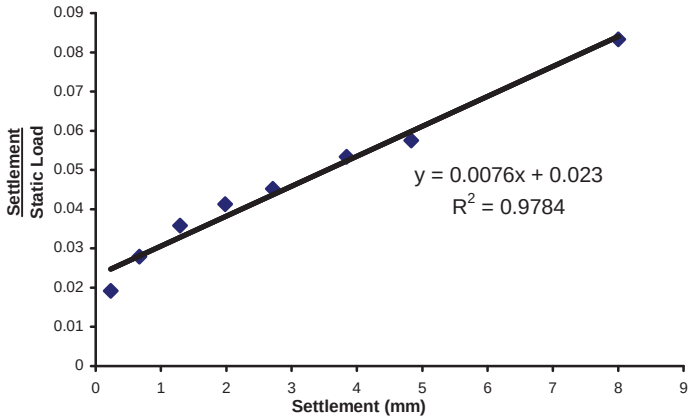


Figure 6.4e Static Load Test Data and Chin's Method for B10-2 (350x350) Concrete Pile

7. Calibration Resistant Factors for Driven Piles in Vietnam

In this chapter, resistance factors for driven piles in Vietnam are developed for different statics methods. Calibration of the resistance factors for each analysis method is presented separately and discussed in detail, including histograms and frequency distribution for each case attained using database was collected in Vietnam by author. For the resistance factors corresponding to a wide range of target reliability indices, a sensitivity analysis is considered in order to provide the designer the freedom to select and determine the degree of conservatism in the design. Efficiency factors are also provided to appropriately compare the economy of different methods. Equivalent factors of safety were back calculated from the developed LRFD resistance factors to compare the ASD approach and determine the percentage of gain in the pile capacity when using the LRFD approach. All the regionally developed resistance factors are thus compared with the current design specifications.

7.1 Procedure to Calibrate Resistance Factors for Driven Piles

- Collect the static load tests and soil profile for driven piles in North, Central and South Vietnam.
- Calculate the nominal capacity by using different methods
- Interpret the static load tests to find the real capacity of driven piles by using the Chin's method and Davission's method.
- Calculate the bias factor $\lambda_{Ri} = R_{mi} / R_{ni}$
- Calculate the mean, λ_R, and the coefficient of variation, COV, of the random series λ_{Ri}.
- Calibrate the resistance factor by using First Order Second Method (FORM), First Order Reliability Method (FORM) and Monte Carlo simulation

7.2 Collection of Driven Piles in Vietnam

The calibration resistance factor process for driven piles in Vietnam requires an extensive data base. From 2008 to 2012 the author collected 275 static load tests and soil profiles for driven pile from North, Central and South of Vietnam. The list of all piles including locations, depth and cross section of piles can be found in table E1 in appendix E. Almost data for driven pile from the North Plain (NP), Central Plain (CP) and South Plain (SP) of Vietnam.

7.3 Measurement capacity of driven piles

Chin method, 1" settlement's criterion and Davission's criterion were used to interpret the static load test data for driven pile in North, Central and South of Vietnam and the result shown detail in Table E1 in appendix E. The Fig 7.1a and Fig 7.1b show the relationship among 80% Chin method, 1" settlement and Davission's criterion for 275 driven piles statics load test. Davission's criterion is used to determine the capacity for the driven piles, since Davission's capacity is closed to both 80% Chin and 1" settlement's capacity.

7.4 Nominal Capacity of driven piles

As mentioned in Chapter 3, eight different pile static analysis methods were used for predicting the design nominal capacity of concrete piles in this research. These methods included: α- Tomlinson, α-API, λ, β, Nordlund, Thurman, Meyerhof SPT, and Shmertmann SPT method. Theα, β, λ, Nordlund and Thurman method use the friction angle φ and/or the undrained shear strength Su or the over-consolidation ratio OCR, but most of the soil data from the database are from SPT tests. Therefore, the soil parameters were mainly calculated based on the corrected SPT N-values and using the soil correlations previously mentioned in Chapter 3. Spreadsheets were created for each method in order to predict the capacity of the 273 concrete piles.

7.4.1 Nominal Capacity of Concrete Piles in Cohesionless Soils

The Nordlund and Thurman method were used to get the nominal capacity of driven pile in sand by using the correlation between Nspt and the friction angle of sand by Peck, Hanson & Thornburn and Schmertmann and the result can be found in table E-3 in appendix E. Fig 7.1a and 7.1b show the prediction capacity by using the correlation from Peck is closer to Davission's capacity than Schmertmann Fig 7.1c and 7.1d show the prediction capacity from empirical method including Schmertmann SPT and Meyerhof SPT and measure capacity are closed

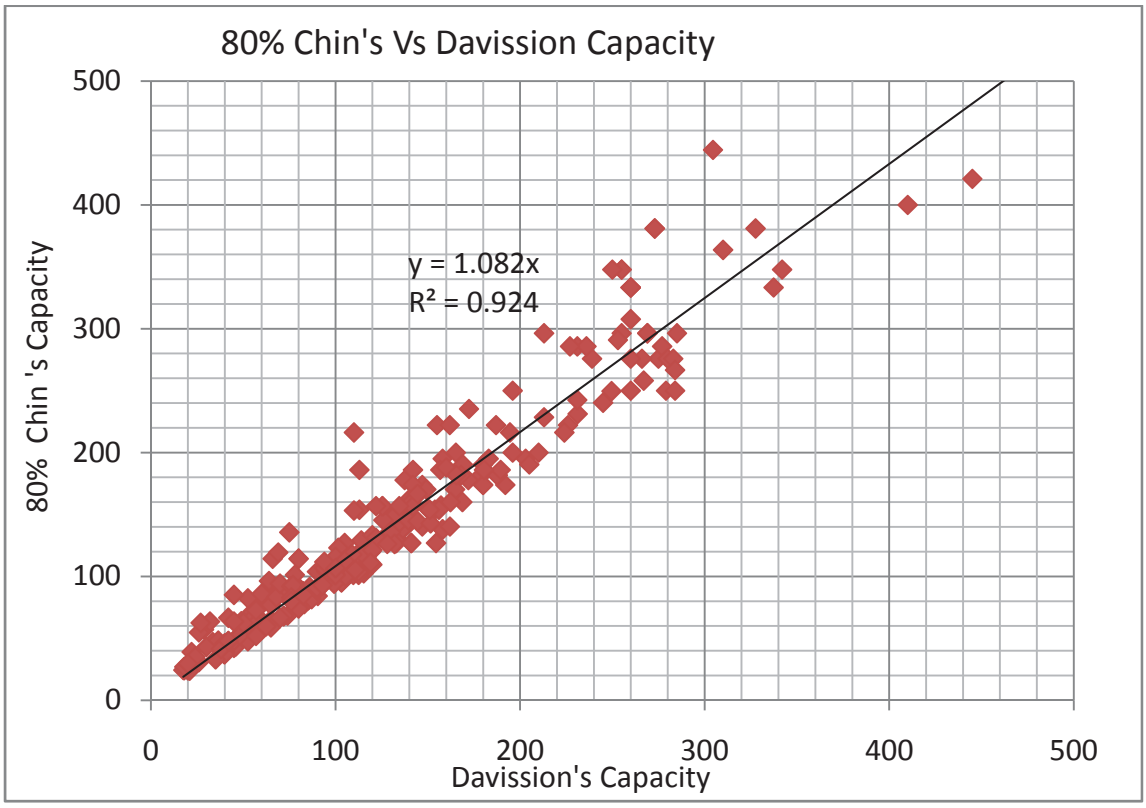


Figure 7.1a Measure Capacity Davisson's versus 80% Chin Method

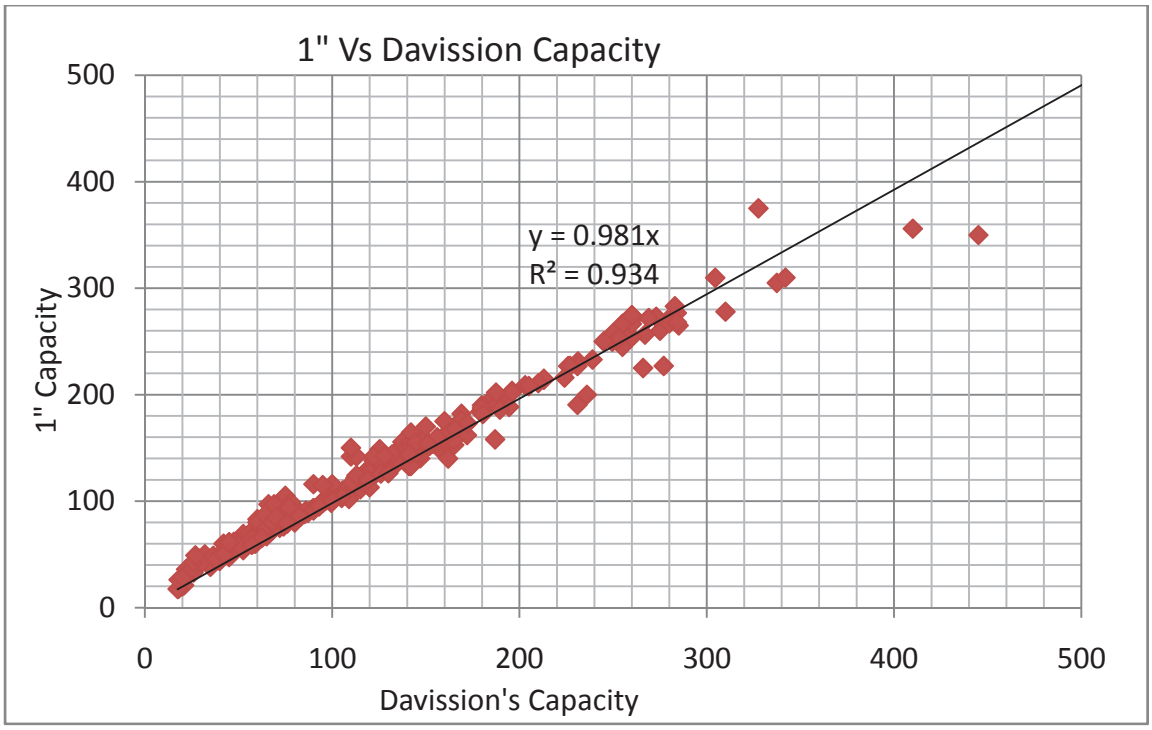
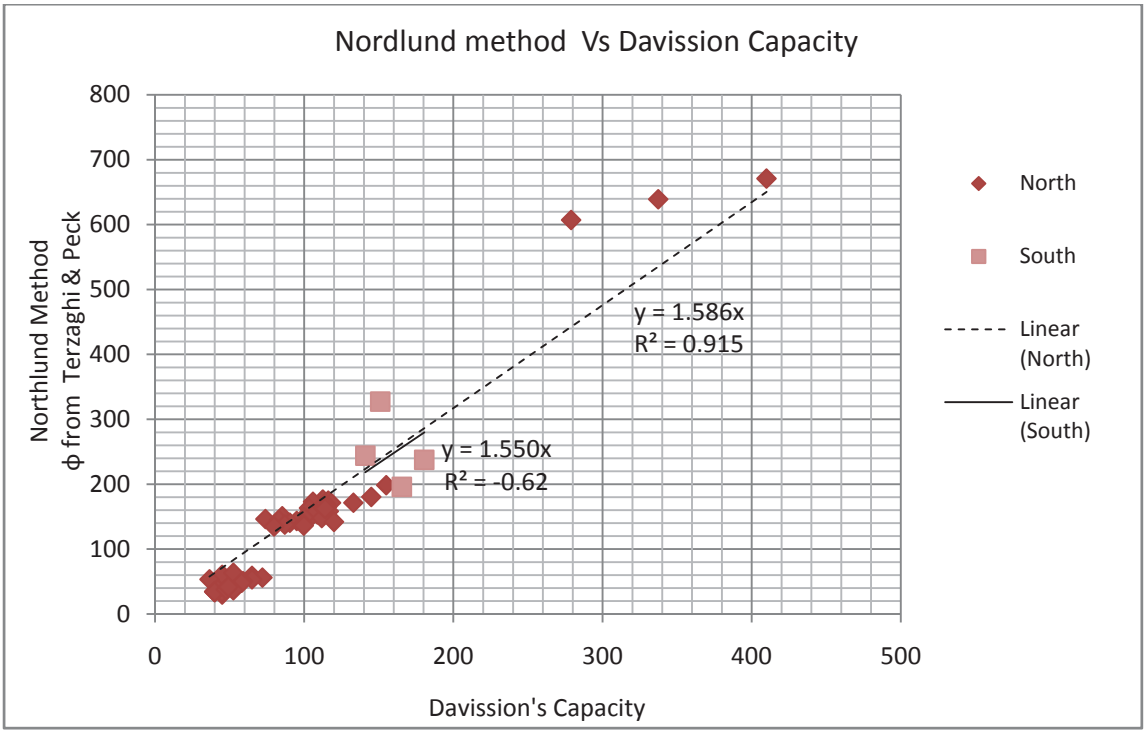
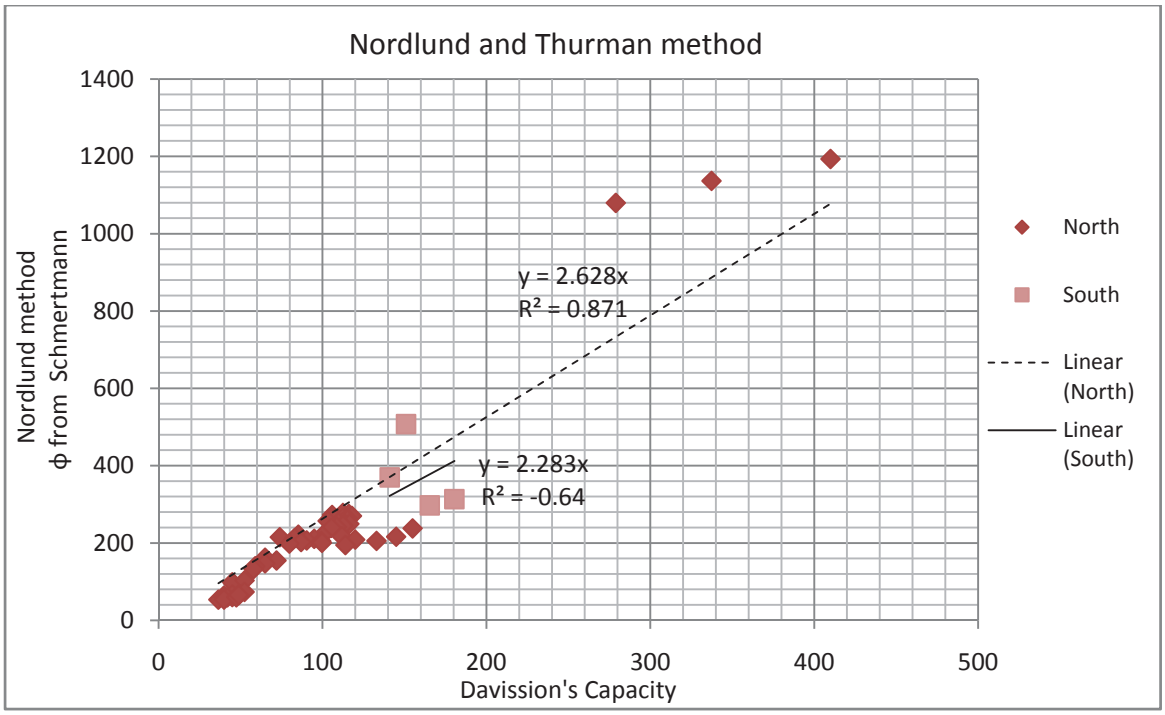


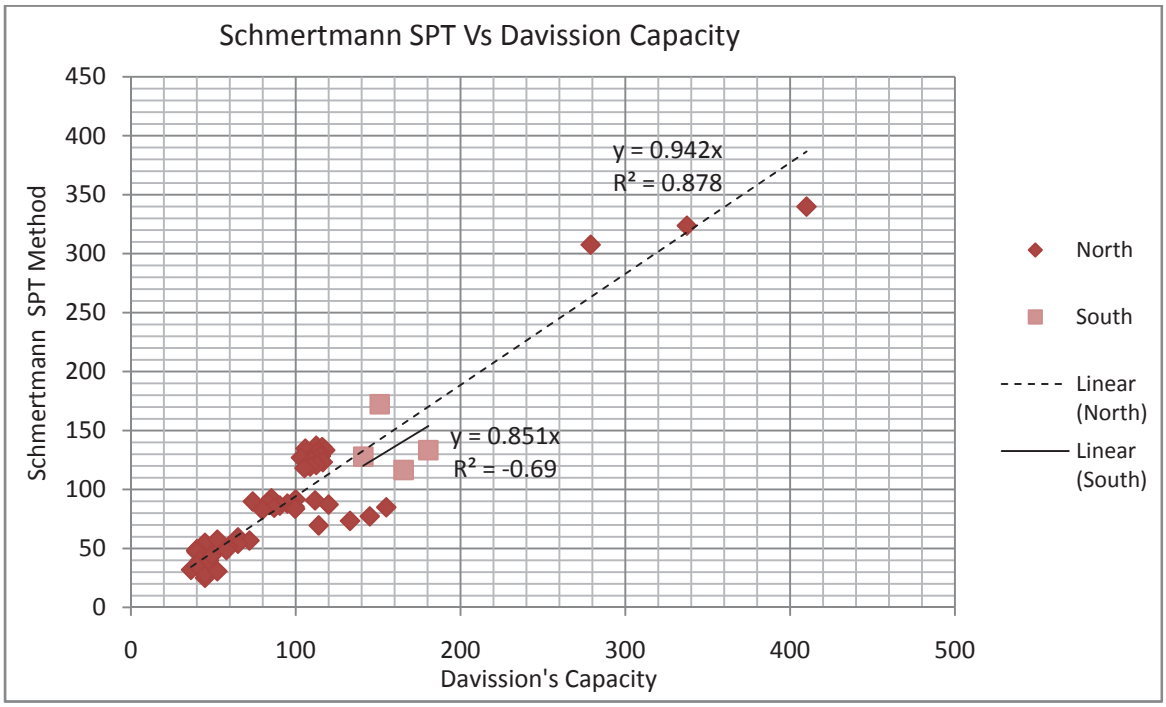
Figure 7.1b Measure Capacity Davisson's versus 1" settlement



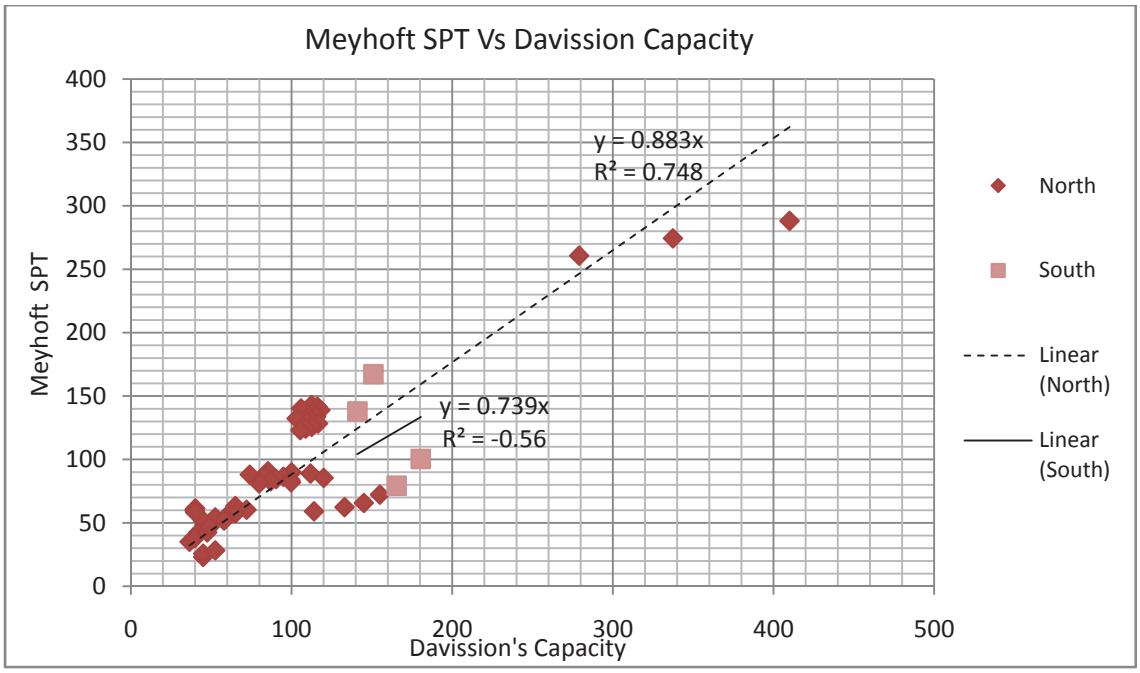
Figures 7.2a: Prediction Capacity using Nordlund method vs. Measure Capacity of Concrete Piles in Cohesionless Soils (North and South of Vietnam)



Figures 7.2b: Prediction Capacity using Nordlund method vs. Measure Capacity of Concrete Piles in Cohesionless Soils (North and South of Vietnam)



Figures 7.2c: Prediction Capacity using Schmertmann SPT method vs. Measure Capacity of Concrete Piles in Cohesionless Soils (North, Central and South of Vietnam)



Figures 7.2d: Prediction Capacity using Meyerhof SPT method vs. Measure Capacity of Concrete Piles in Cohesionless Soils (North, Central and South of Vietnam)

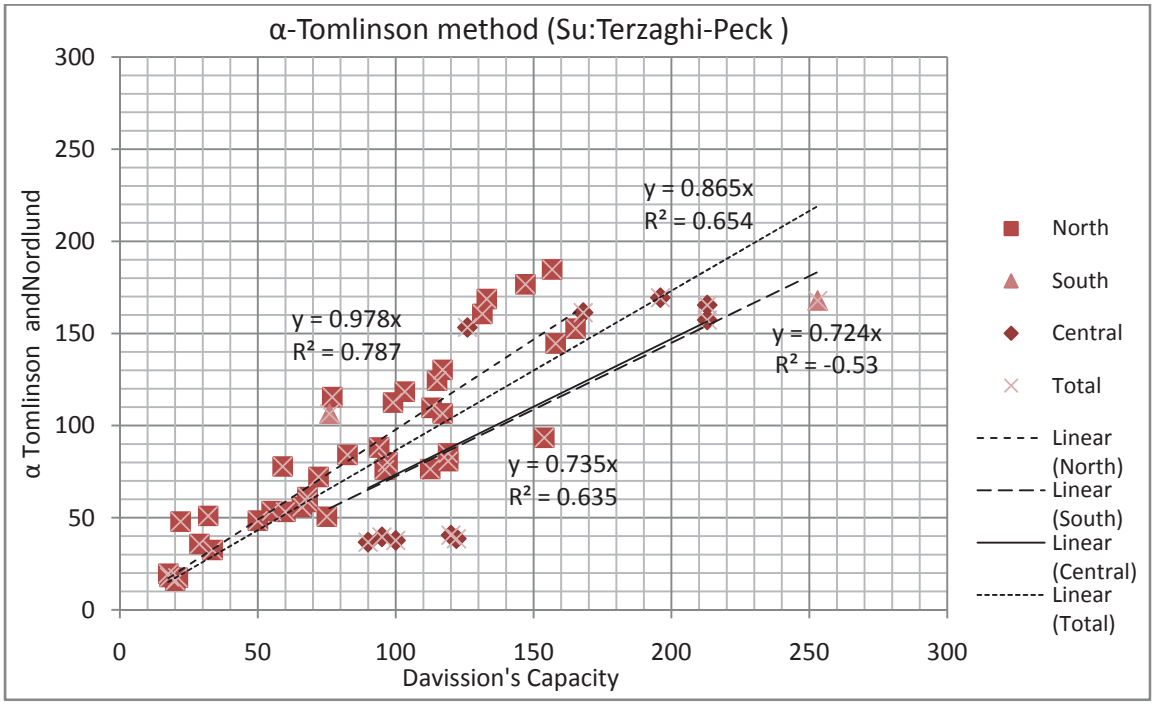
7.4.2 Nominal Capacity of Concrete Piles in Cohesive Soils

The α-Tomlinson method, α-API method, λ method, β-Burland, Schmertmann SPT method were used to get the nominal capacity of driven pile in cohesive soil by using the correlation between Nspt and the un-drain shear strength Su of clay by Terzaghi and Peck (1967) and Hara (1974). The prediction capacity of driven piles in cohesive soil can be founded in table E-3 in appendix E. Fig 7.2a to 7.2g show the prediction capacity by using the correlation between Nspt and Su from Terzaghi and Peck is underestimate and from Hara is over estimate with all method using in calculate the nominal capacity for driven piles in cohesive soil. Fig 7.2h shows the prediction capacity from empirical Schmertmann SPT method is closed to measure capacity

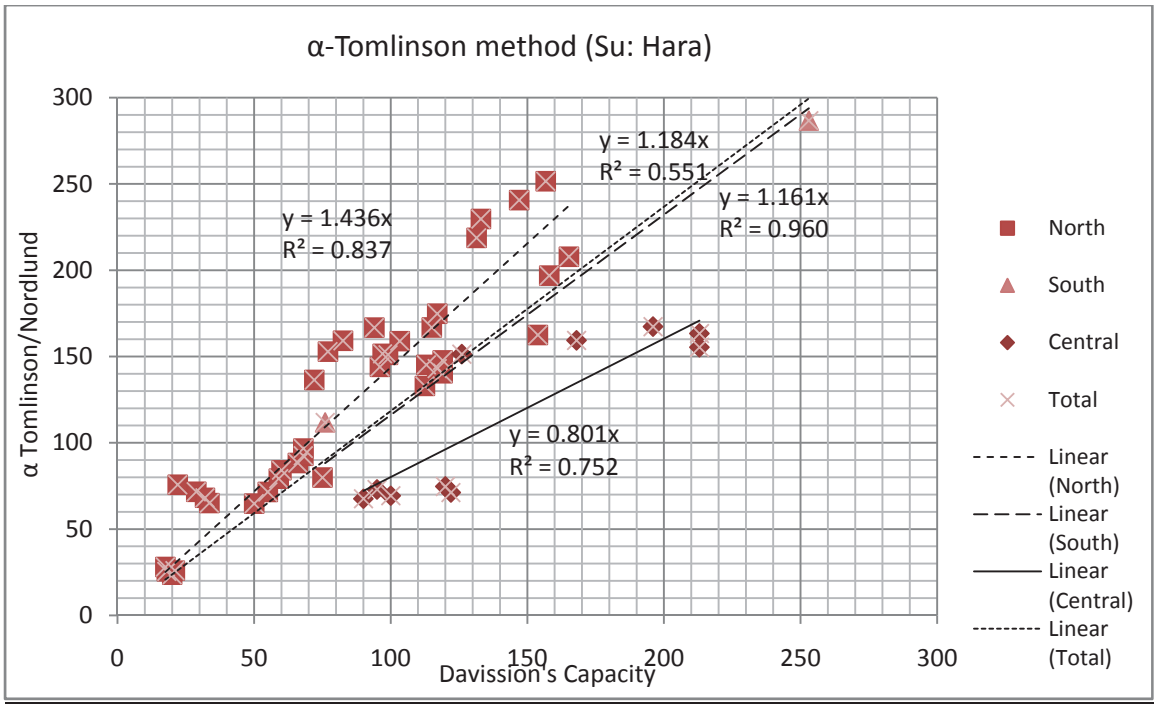
7.4.3 Nominal Capacity of Concrete Piles in Mixed Soils

Seven different pile static analysis methods were used for predicting nominal capacity of concrete piles in mixed soil including: α-Tomlinson, α-API, λ, β-Burland, Nordlund, Thurman, Schmertmann SPT method by using the correlation

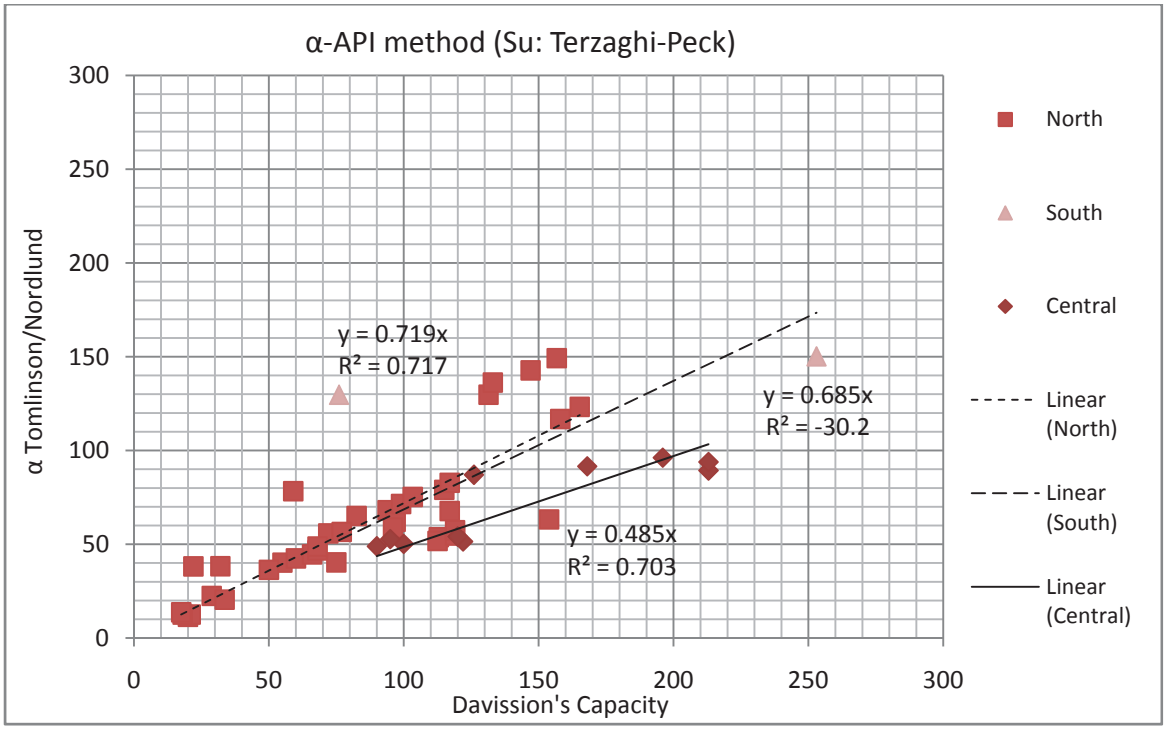
between Nspt and the un-drain shear strength Su of clay by Terzaghi and Peck (1967) or Hara (1974) and friction angle of sand by Peck, Hanson and Thornburn or Schmertmann. The predicted capacity of driven piles in mixed soil is in table E-5 in appendix E. Fig 7.3a to 7.2g show the prediction capacity by using the correlation friction angle from Peck, Hanson and Thornburn is closer to measure capacity and from Schmertmann is over estimate.



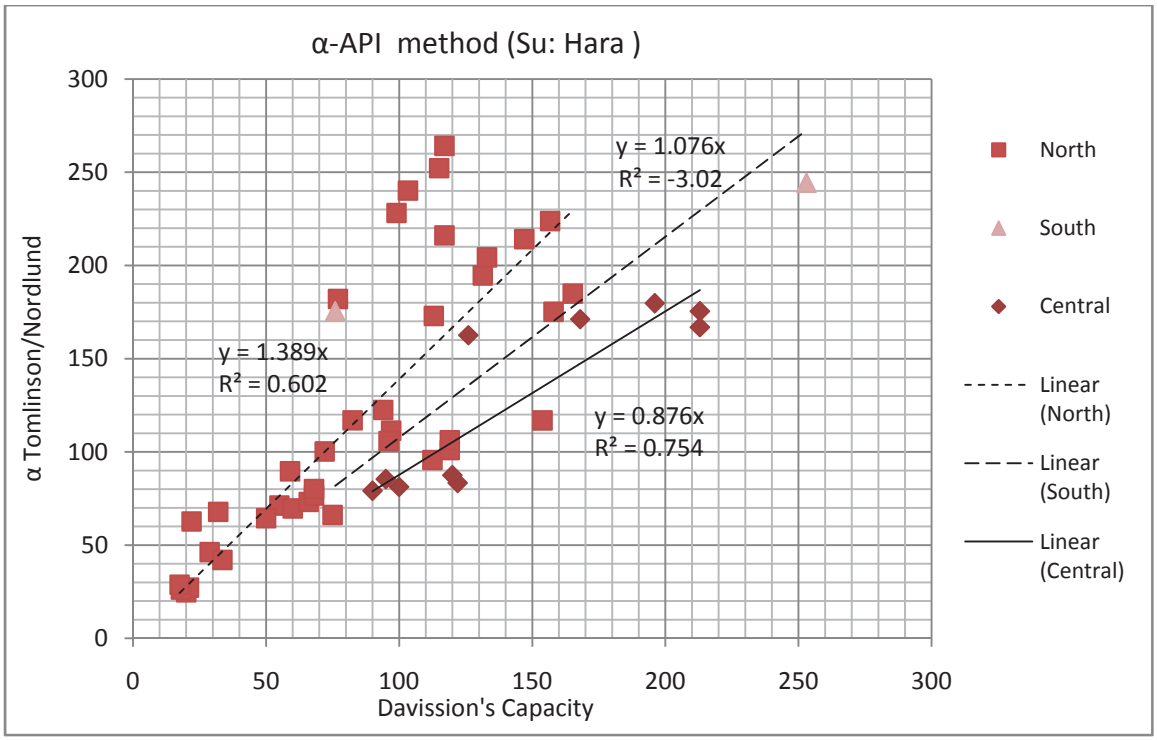
Figures 7.3a: Prediction Capacity using α-Tomlinson method vs. Measure Capacity of Concrete Piles in Cohesive Soils- Su from Terzaghi-Peck in North, Central and South of Vietnam



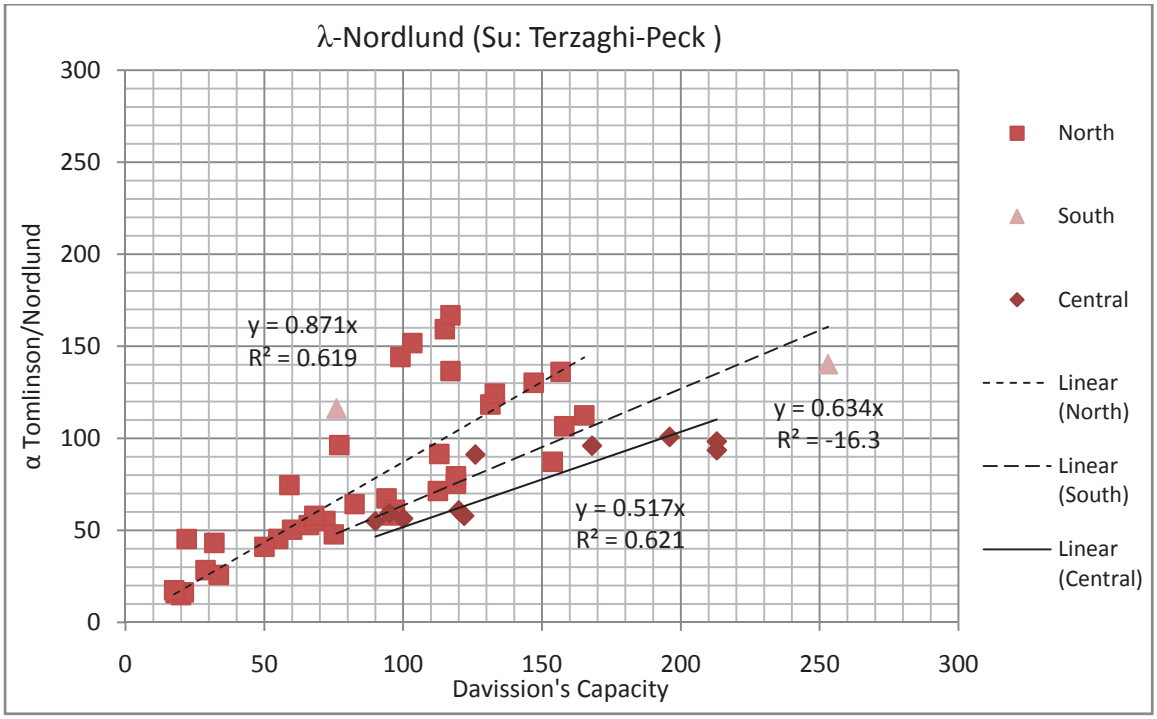
Figures 7.3b: Prediction Capacity using α-Tomlinson method vs. Measure Capacity of Concrete Piles in Cohesive Soils-Su from Hara in North, Central and South of Vietnam



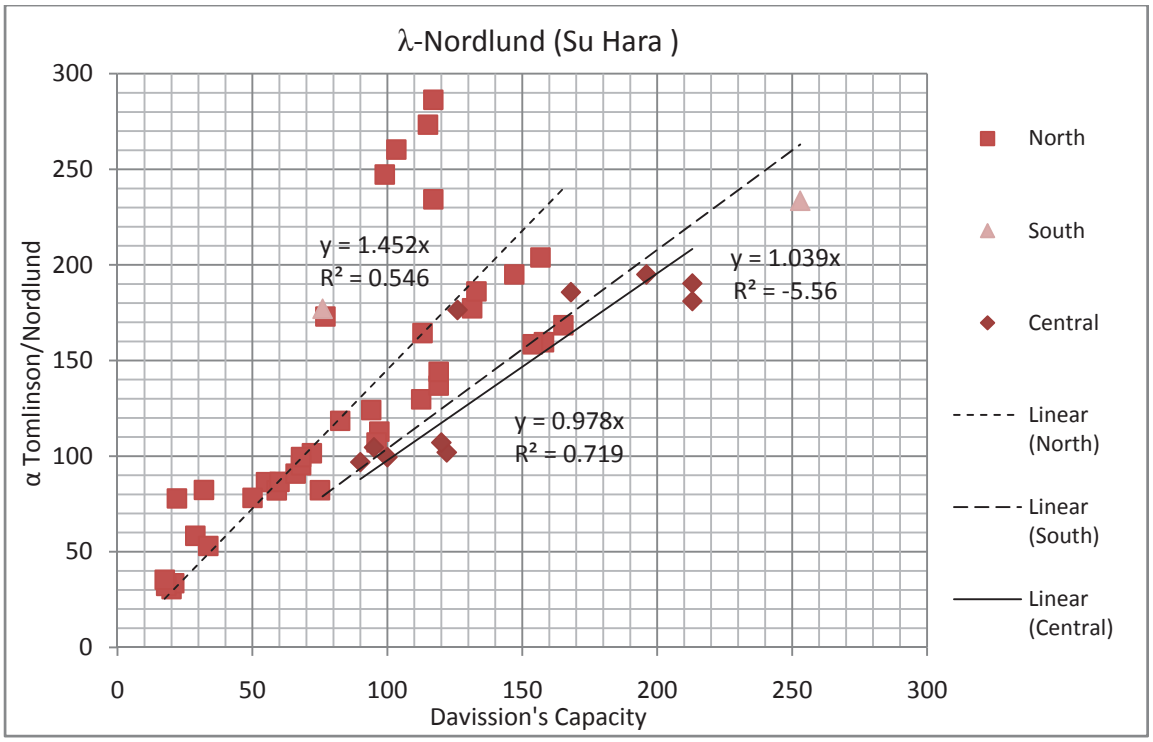
Figures 7.3c: Prediction Capacity using α-API method vs. Measure Capacity of Concrete Piles in Cohesive Soils-Su from Terzaghi-Peck in North, Central and South of Vietnam



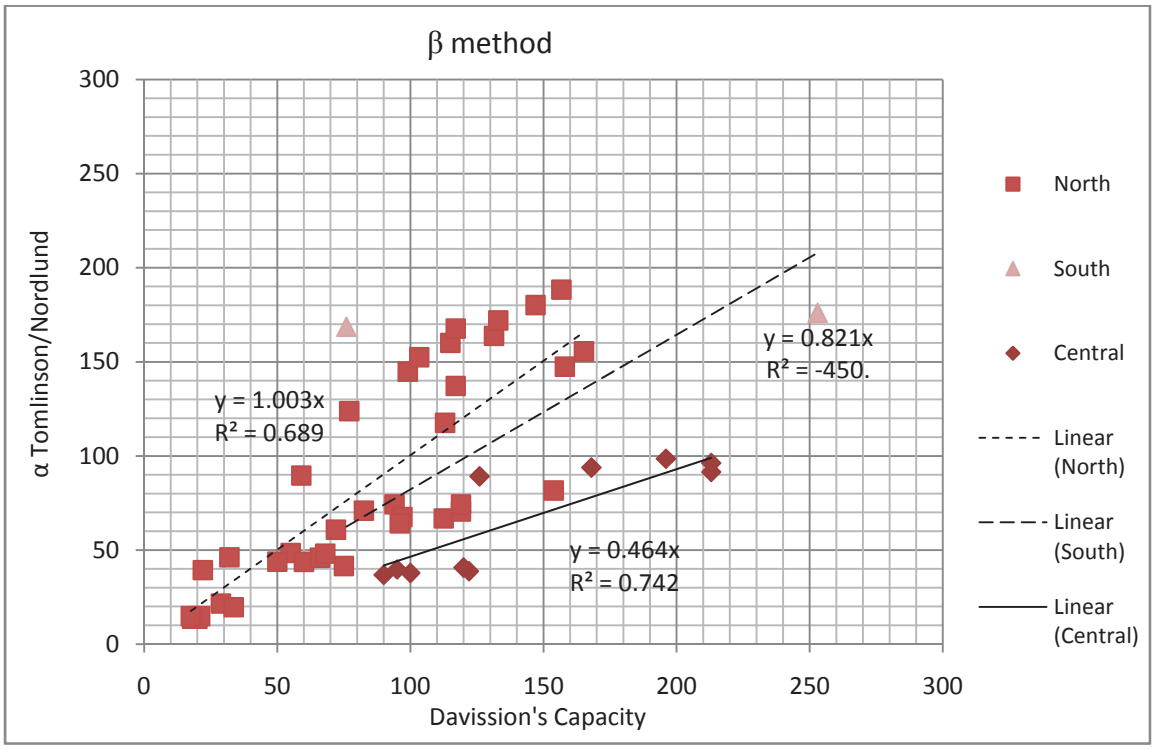
Figures 7.3d: Prediction Capacity using α-API method vs. Measure Capacity of Concrete Piles in Cohesive Soils-Su from Hara in North, Central and South of Vietnam



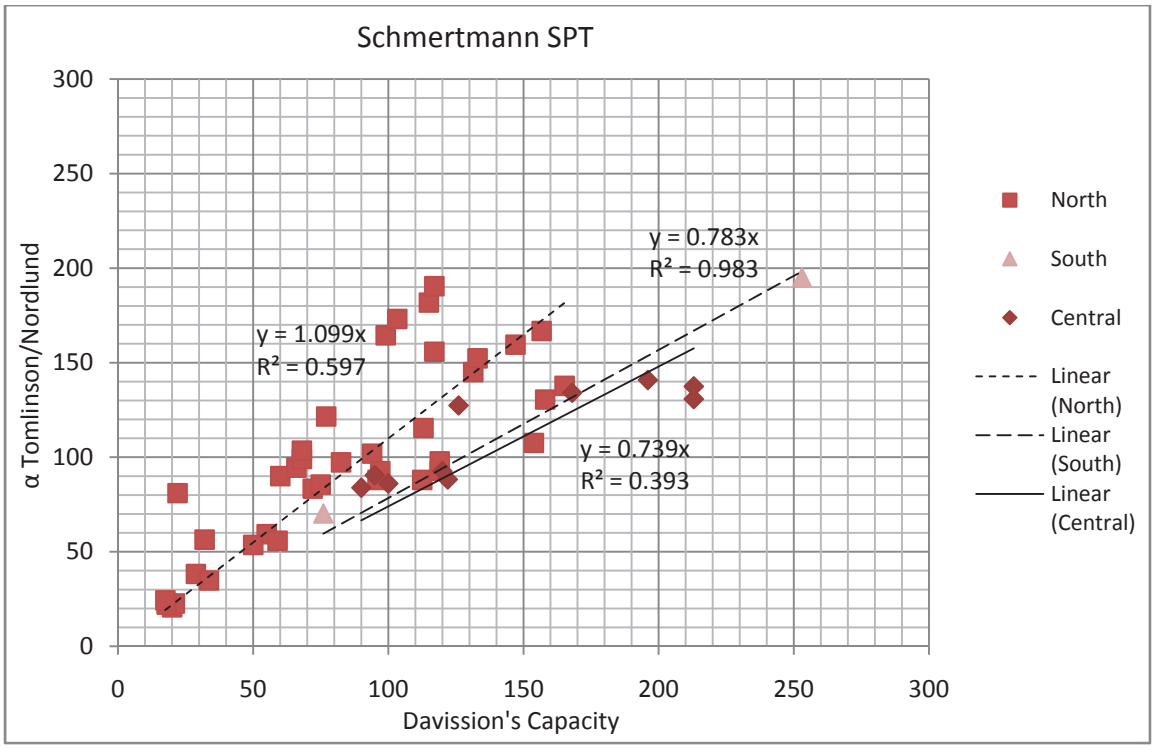
Figures 7.3e: Prediction Capacity using λ method vs. Measure Capacity of Concrete Piles in Cohesive Soils-Su from Terzaghi and Peck in North, Central and South of Vietnam



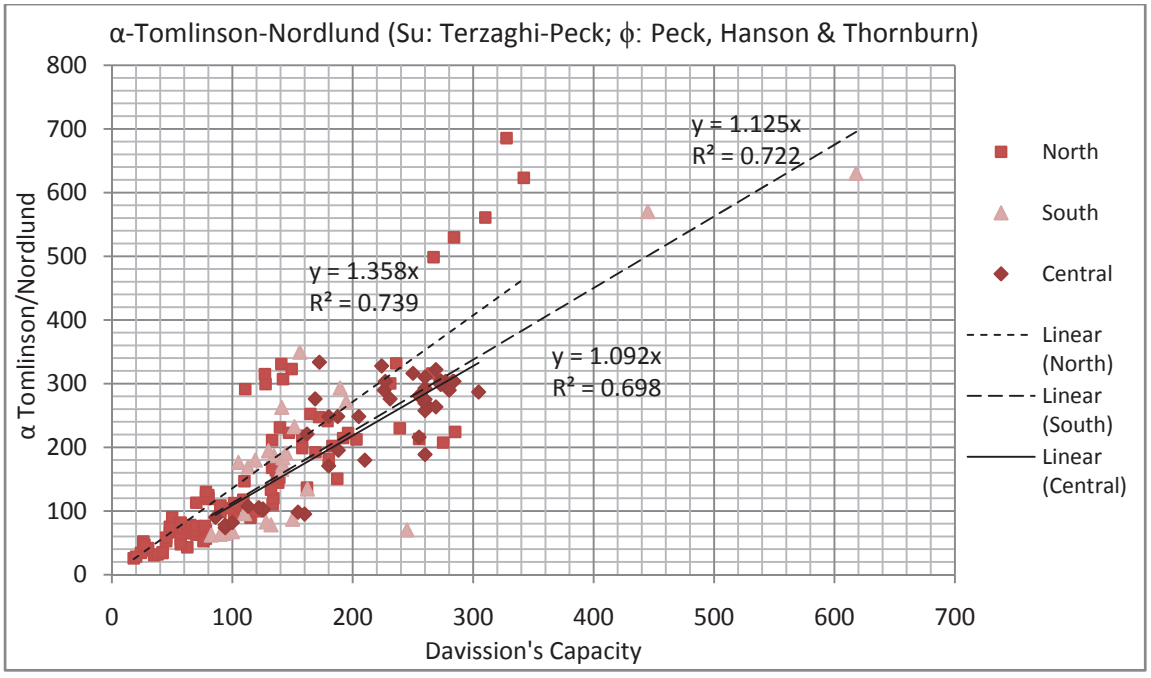
Figures 7.3f: Prediction Capacity using λ method vs. Measure Capacity of Concrete Piles in Cohesive Soils-Su from Hara (North, Central and South of Vietnam)



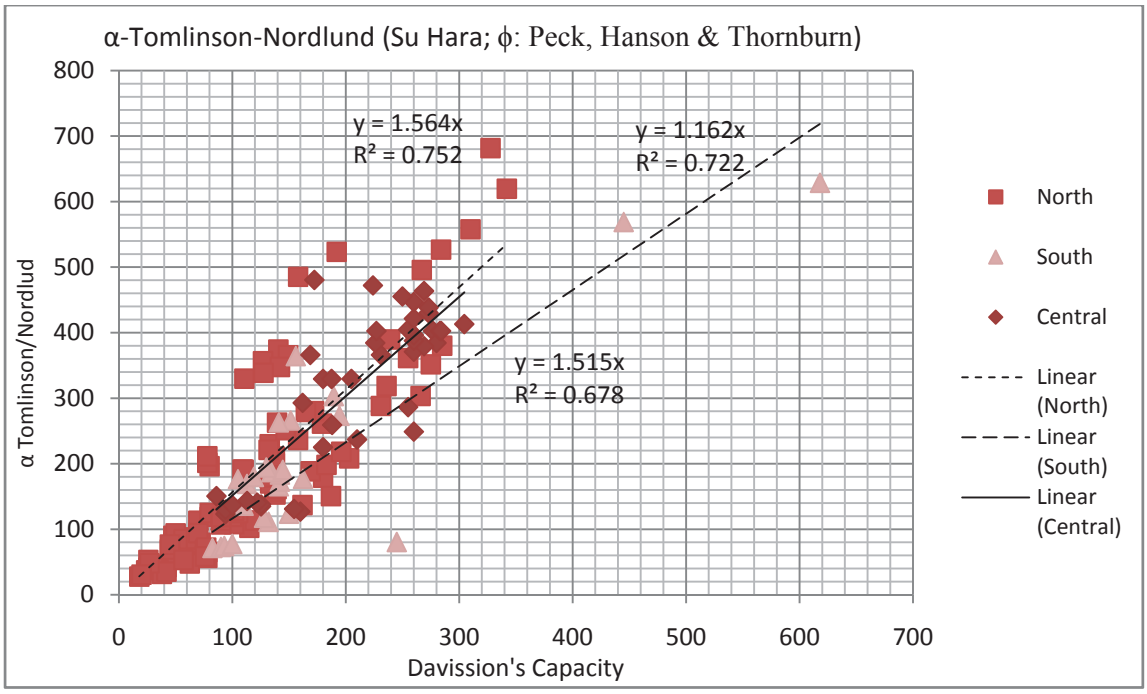
Figures 7.3g: Prediction Capacity using β method vs. Measure Capacity of Concrete Piles in Cohesive Soils (North, Central and South of Vietnam)



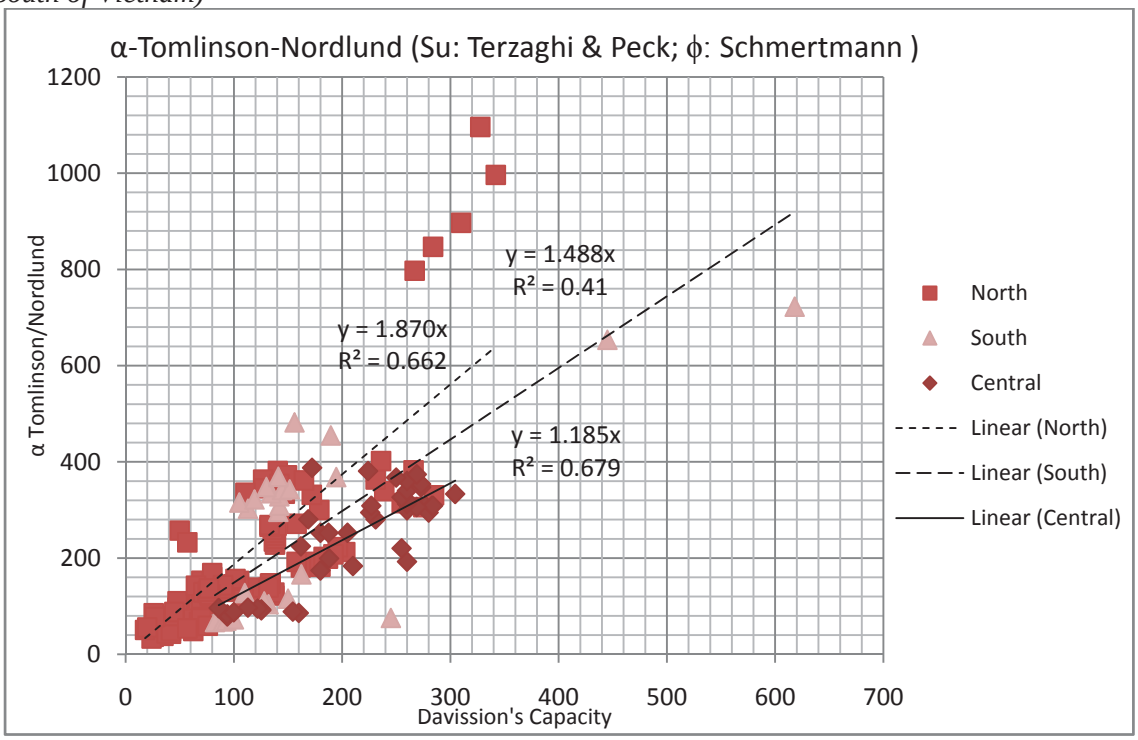
Figures 7.3h: Prediction Capacity using Schmertmann SPT method vs. Measure Capacity of Concrete Piles in Cohesive Soils (North, Central and South of Vietnam)



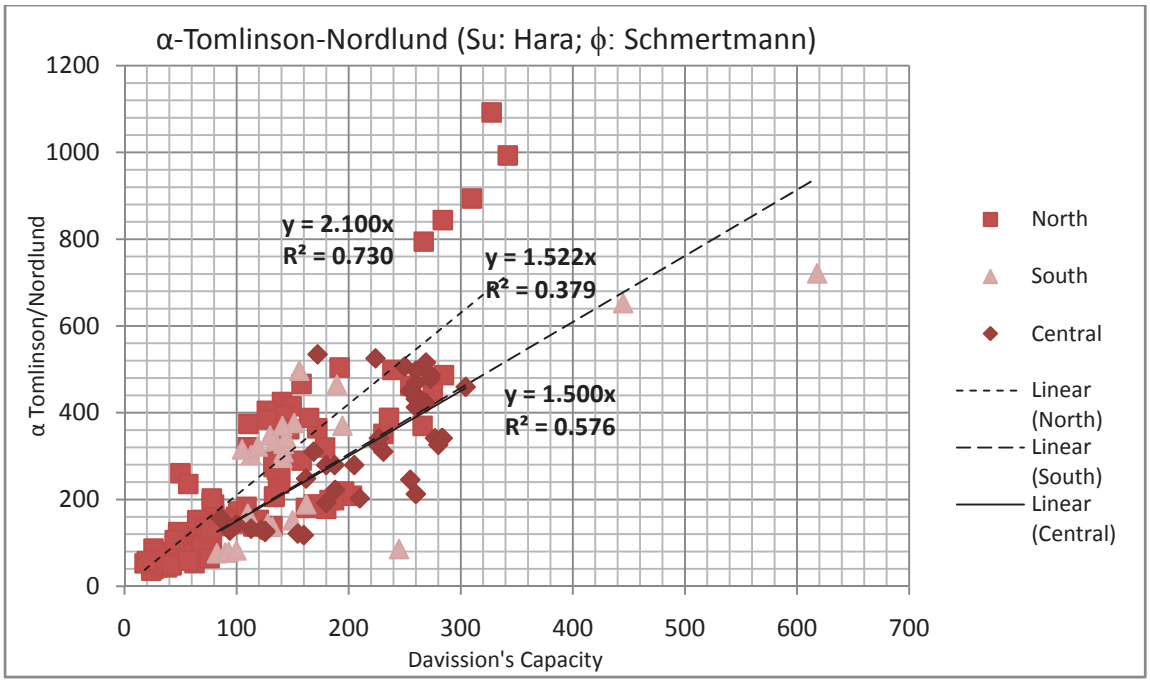
Figures 7.4a1: Prediction Capacity using α-Tomlinson, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils- Su from T-P, φ from P-H-T (North, Central and South of Vietnam)



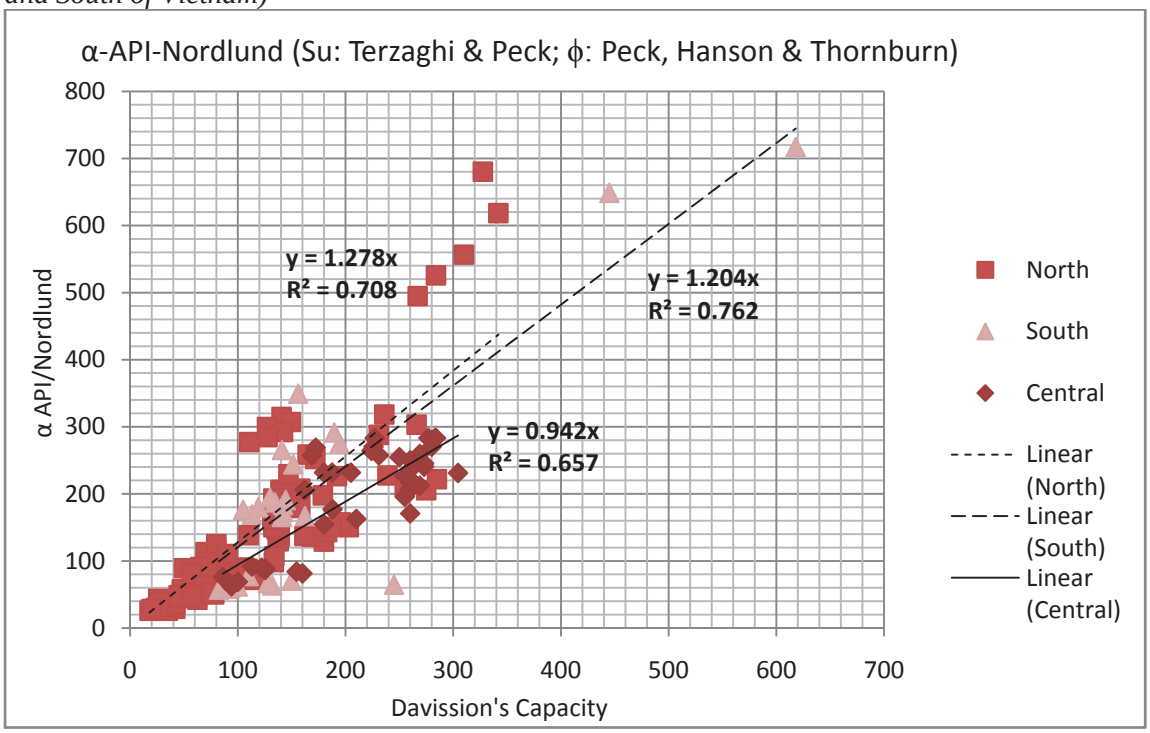
Figures 7.4a2: Prediction Capacity using α-Tomlinson, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils - Su from Hara, φ from P-H-T*(North, Central and South of Vietnam)*



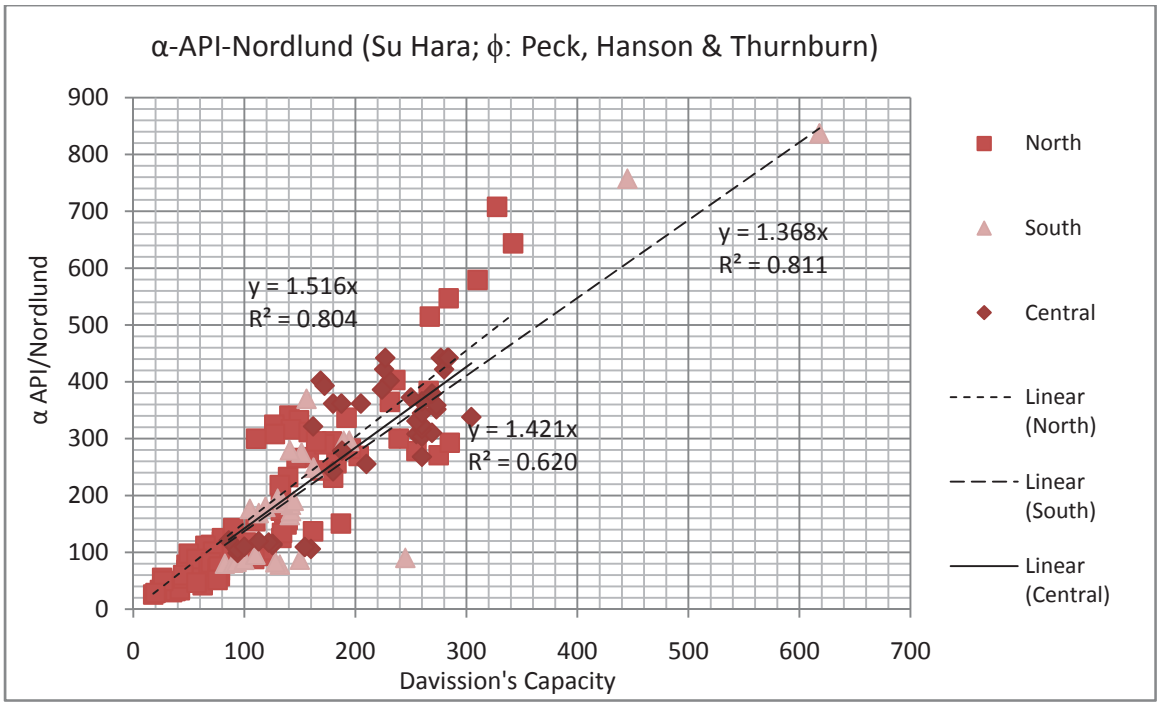
Figures 7.4a3: Prediction Capacity using α-Tomlinson, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils - Su from T-P, φ from Schmertmann *(North, Central and South of Vietnam)*



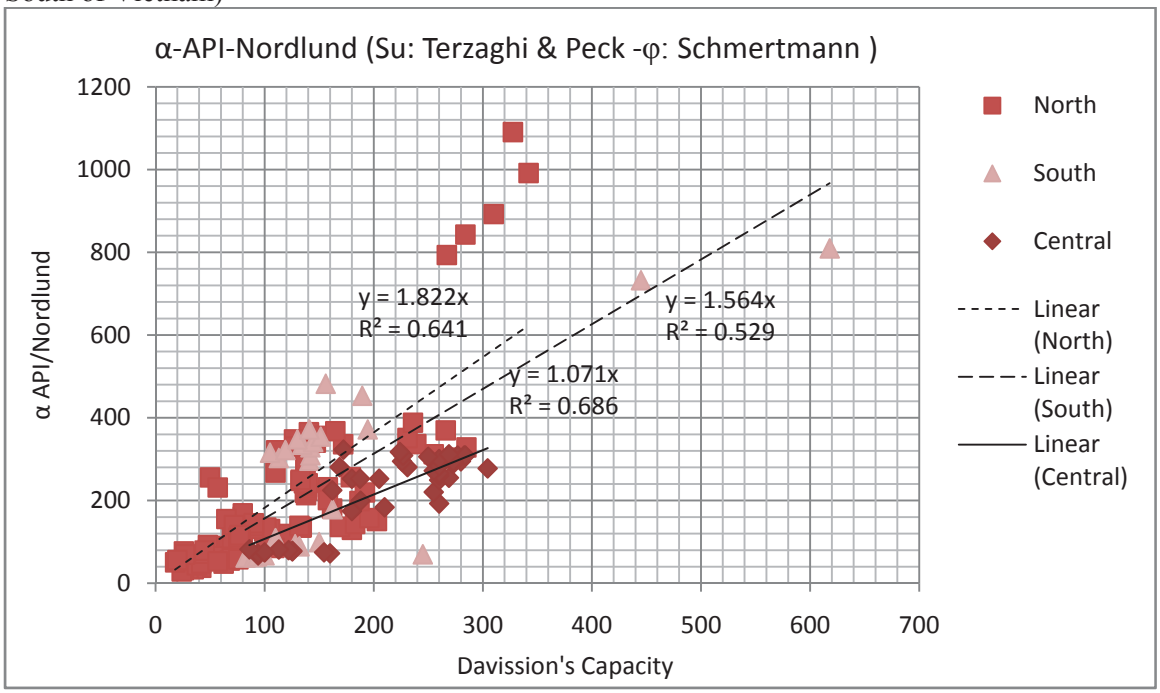
Figures 7.4a4: Prediction Capacity using α-Tomlinson, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils - Su from Hara, φ from Schmertmann *(North, Central and South of Vietnam)*



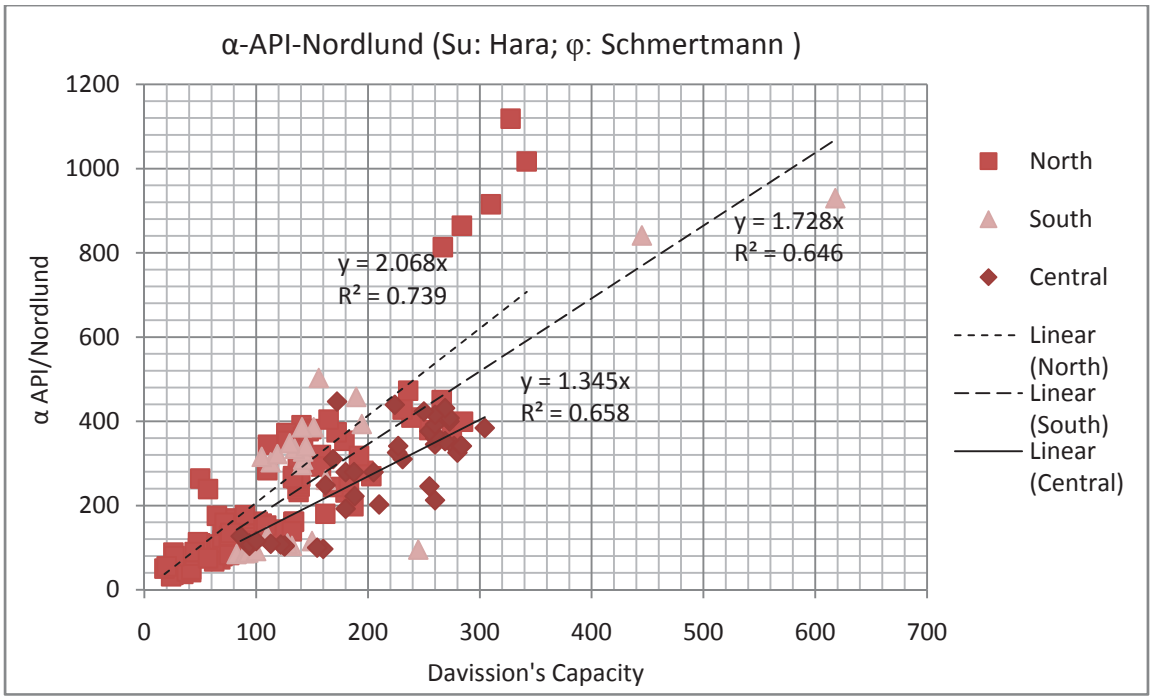
Figures 7.4b1 Prediction Capacity using α-API, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils-Su from T-P, φ from P,H &T(North, Central and South of Vietnam)



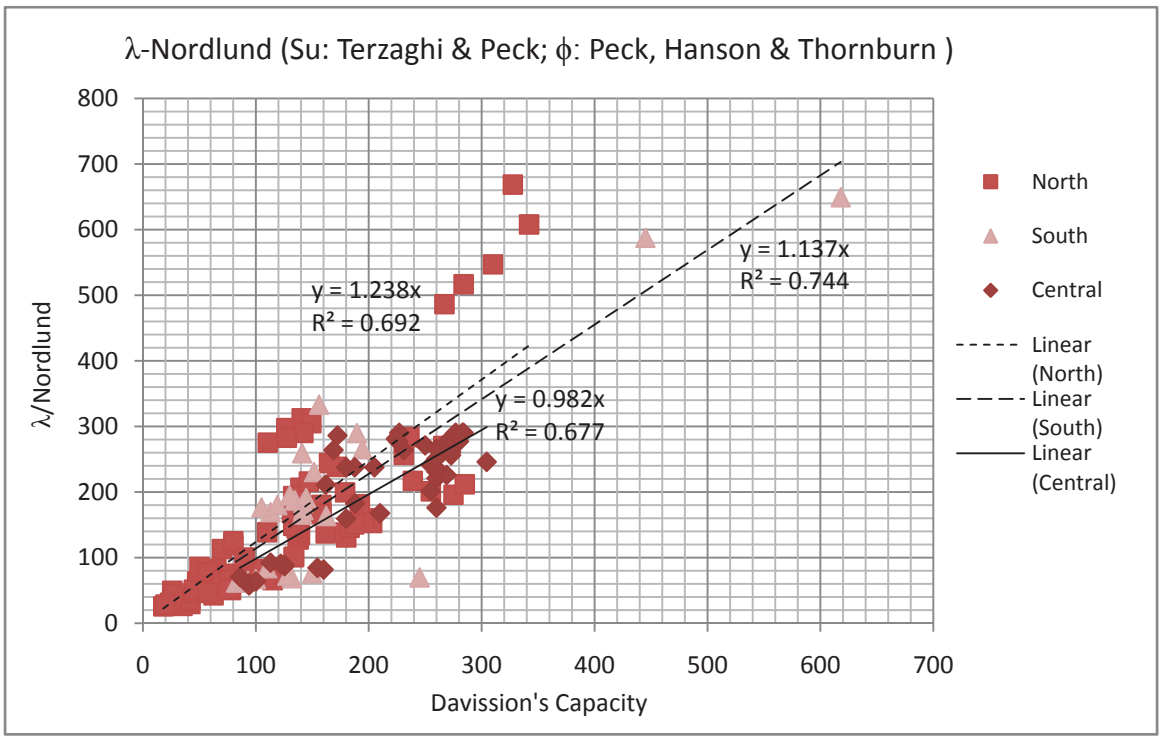
Figures 7.4b2: Prediction Capacity using α-API, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils-Su from Hara, φ from P,H &T (North, Central and South of Vietnam)



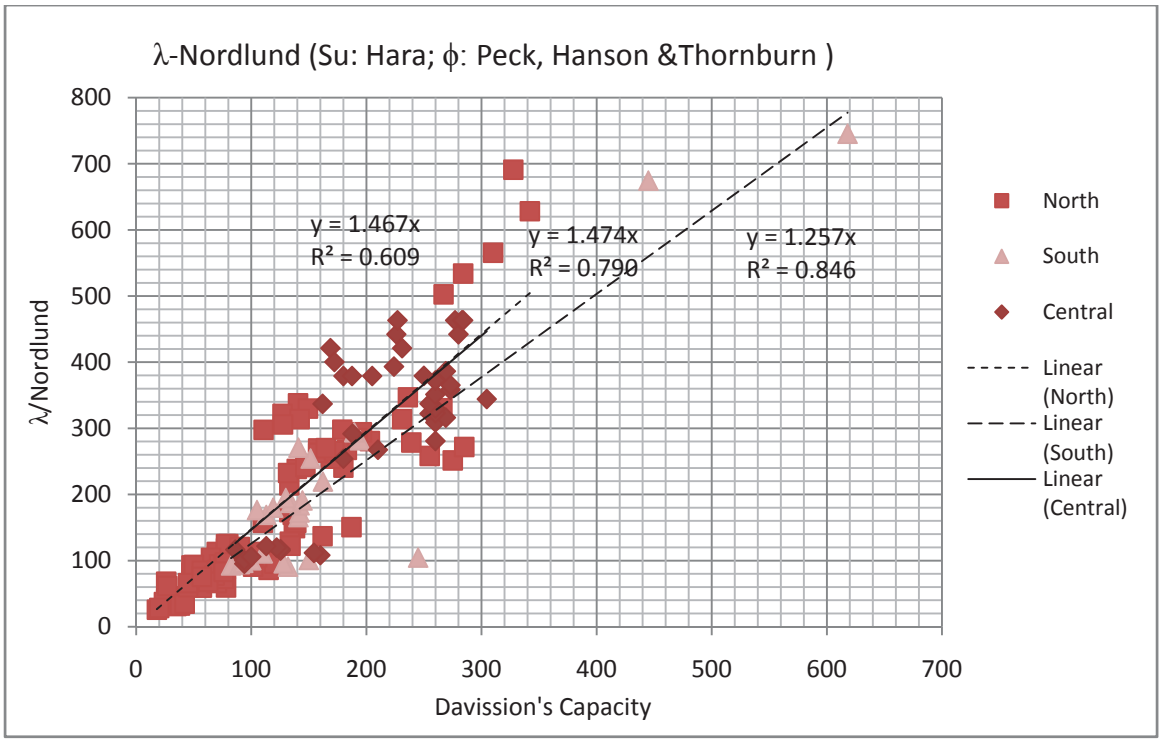
Figures 7.4b3: Prediction Capacity using α-API, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils-Su from T-P, φ: from Schmertmann (North, Central and South of Vietnam)



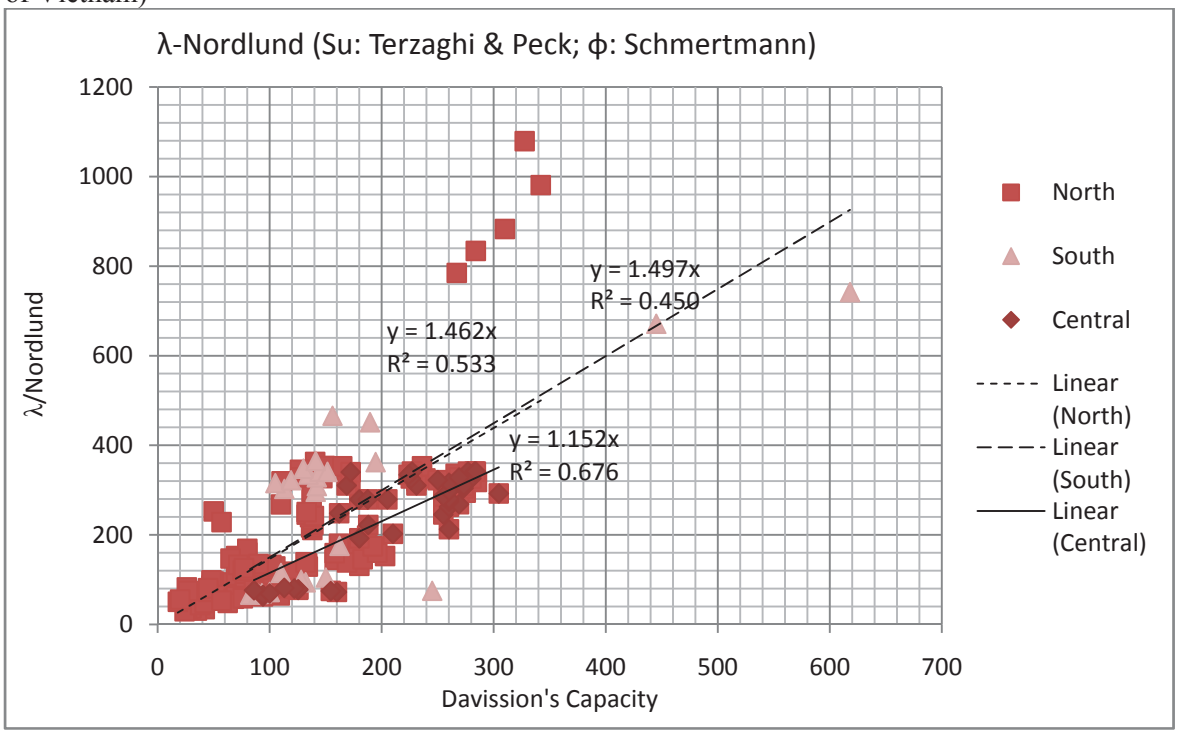
Figures 7.4b4: Prediction Capacity using α-API, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils-Su: Hara; φ: Schmertmann (North, Central and South of Vietnam)



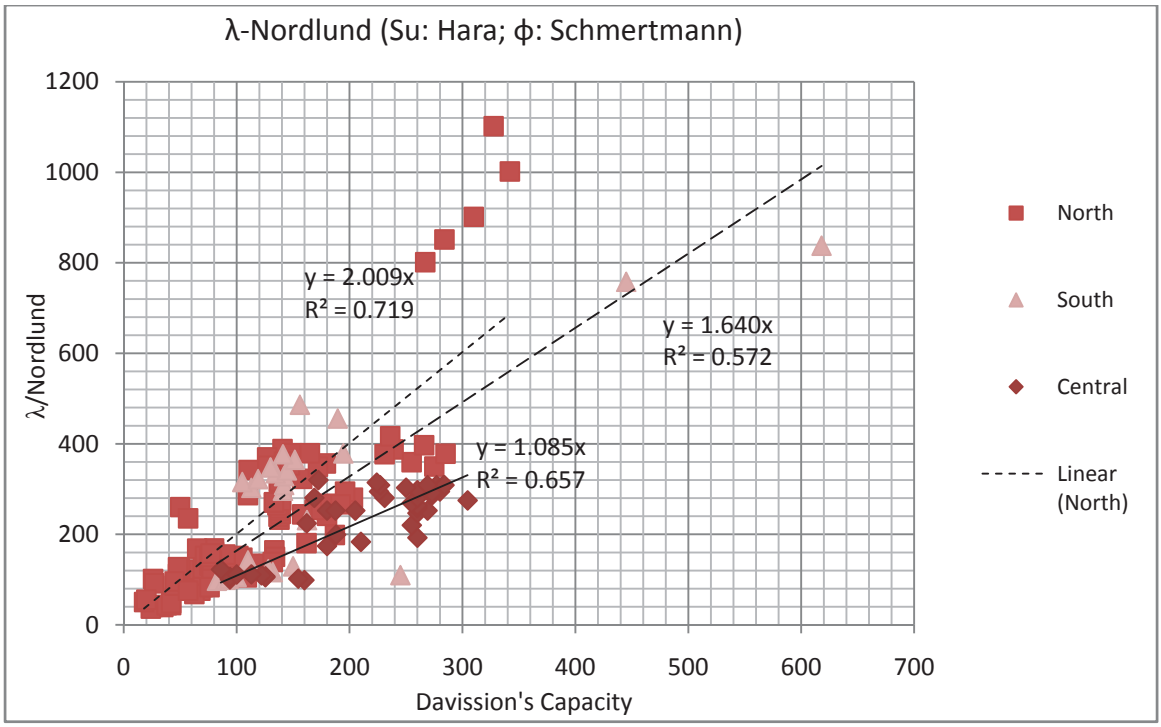
Figures 7.3c1: Prediction Capacity using λ, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils-Su: Terzaghi & Peck; ϕ: Peck, Hanson & Thornburn (North, Central and South of Vietnam)



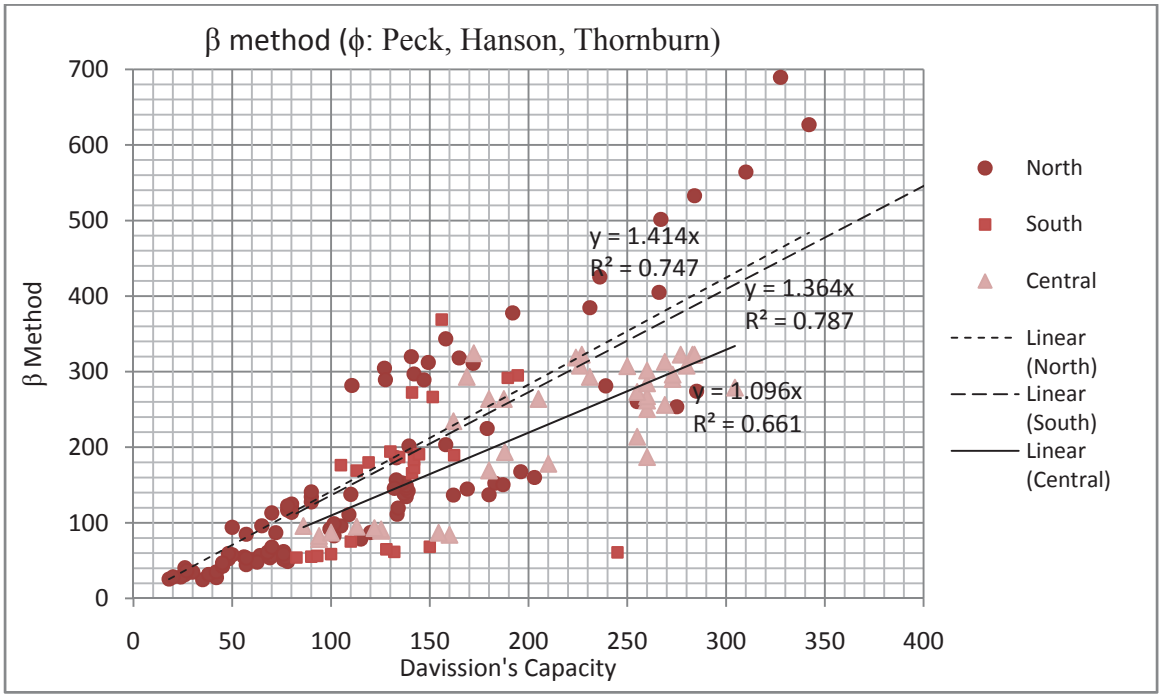
Figures 7.4c2: Prediction Capacity using λ, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils-Su: Hara; ϕ: Peck, Hanson & Thornburn (North, Central and South of Vietnam)



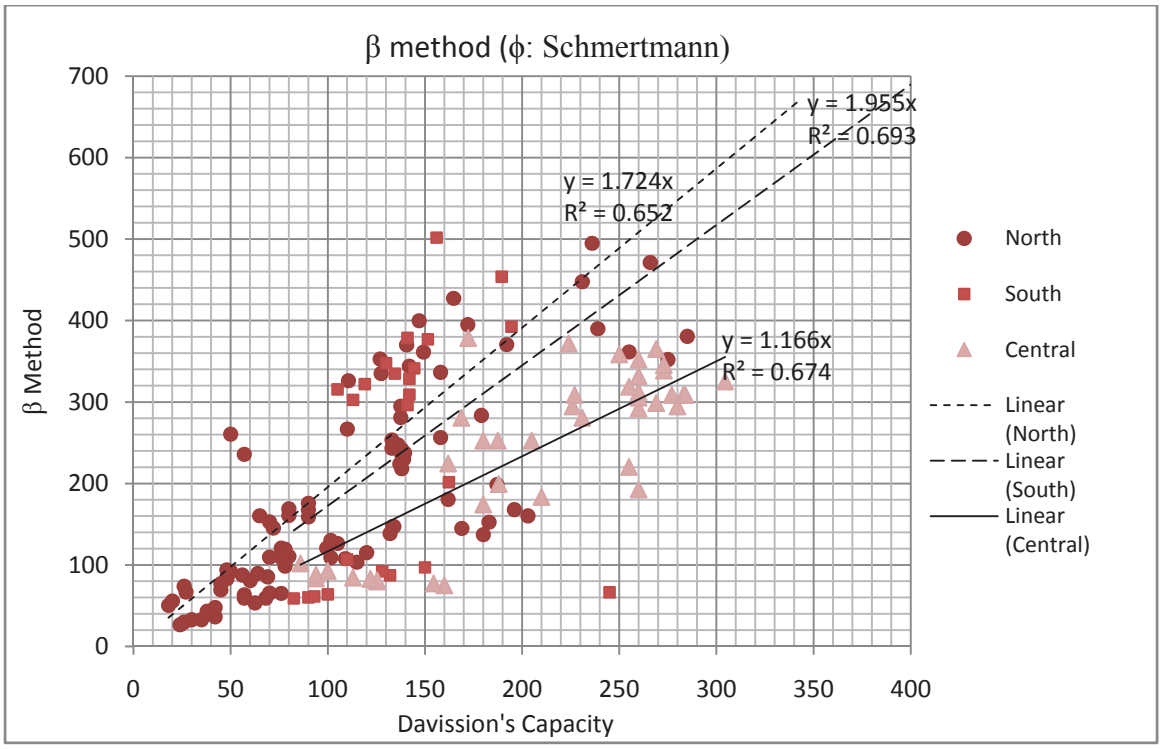
Figures 7.4c3: Prediction Capacity using λ, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils-Su: Terzaghi& Peck; φ: Schmertmann (North, Central and South of Vietnam)



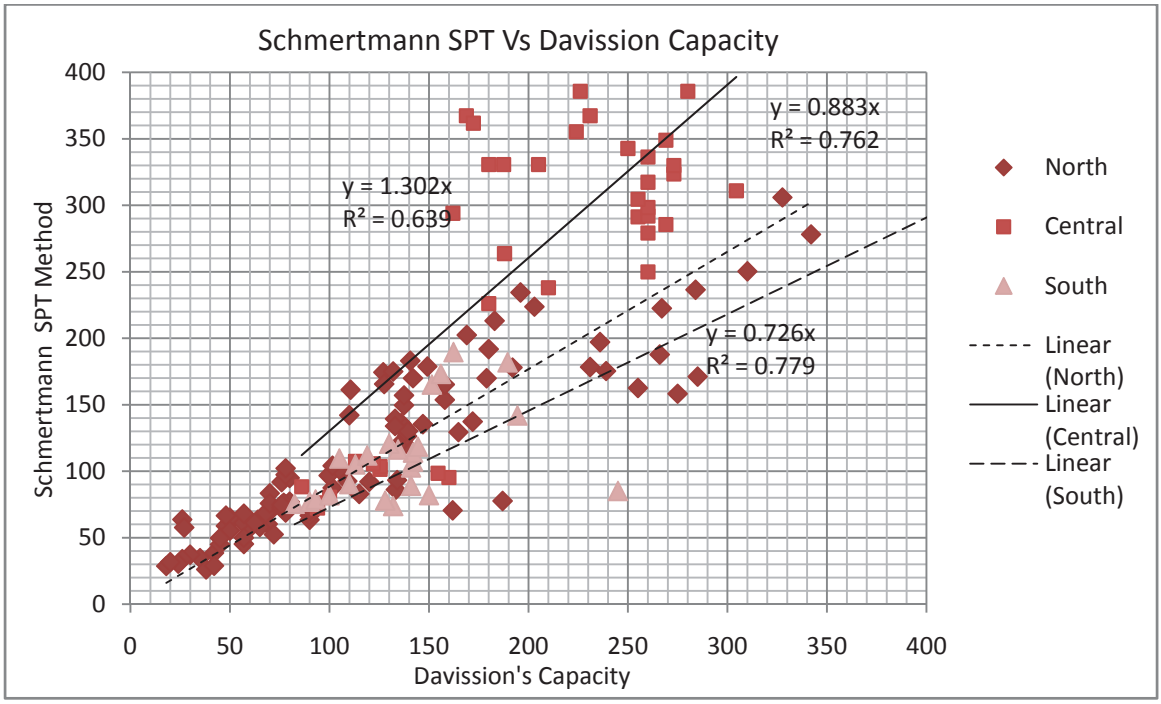
Figures 7.4c4: Prediction Capacity using λ, Nordlund, Thurman method vs. Measure Capacity of Concrete Piles in Mixed Soils-Su: Hara; φ: Schmertmann (North, Central and South of Vietnam)



Figures 7.4d1: Prediction Capacity using β method vs. Measure Capacity of Concrete Piles in Mixed Soils-ϕ: Peck, Hanson, Thornburn-ϕ: Peck, Hanson, Thornburn (North, Central and South of Vietnam)



Figures 7.4d2: Prediction Capacity using β method vs. Measure Capacity of Concrete Piles in Mixed Soils-ϕ: Schmertmann (North, Central and South of Vietnam)



Figures 7.4e1: Prediction Capacity using SPT method vs. Measure Capacity of Concrete Piles in Mixed Soils (North, Central and South of Vietnam

7.5 Calibration of Resistance Factors

As discussed in Chapter 4, there are tree statistical methods used for the LRFD resistance factor calibration including First Order Second Moment (FOSM), First Order Reliability Methods (FORM) and other advanced methods, such as the Monte Carlo simulation, have been used for performing the reliability analyses with assuming a lognormal distribution of the load and resistance Probability Density Functions (PDFs).The author conducted the analysis using both the FOSM and the FORM methods using the data from NHCRP 507 report and the result showed that the difference between FOSM and FORM is relatively small (did not exceed 10% on average) as the FOSM provides slightly conservative resistance factors. Using the equation 7.1 for FOSM and writing the Matlab program by using the theory in chapter 4 for FORM and Monte Carlo simulation to find the resistance factor ϕwith the following parameters: dead load factor-γ_D = 1.25, live load factor-γL = 1.75, dead load bias factor-λ_{QD} = 1.08, live load bias factor-λ_{QL} =1.15, dead load coefficients of variation-COV_{QD} = 0.13 and live load coefficients of variation COV_{QL}= 0.18. Sine dead to live load ratio QD/QL changes from 1-3 and has almost no effect on the resistance factor, this study uses QD/QL = 1.

$$\phi = \frac{\lambda_R\left(\gamma_{Q_D}\frac{Q_D}{Q_L}+\gamma_{Q_L}\right)\sqrt{\left(1+COV_{Q_D}{}^2+COV_{Q_L}{}^2\right)/\left(1+COV_R{}^2\right)}}{\left(\lambda_{Q_D}\frac{Q_D}{Q_L}+\lambda_{Q_L}\right)\exp(\beta_T\sqrt{\ln\left[\left(1+COV_R{}^2\right)\left(1+COV_{Q_D}{}^2+COV_{Q_L}{}^2\right)\right]}} \quad (7.1)$$

As commented in Chapter 4, the targeted β values in this study were chosen to be similar to those used in the 2012 AASHTO-LRFD specifications and the NCHRP report 507, i.e., β = 2.33 (Pf = 1%) for redundant pile groups (consisting of five or more piles/cap), and β = 3.0 (Pf = 0.1%) for non-redundant pile groups (less than five piles/cap). However, the LRFD resistance factors will be calculated herein for a wider range of β, providing the freedom of selecting any other target reliability and corresponding resistance factors for pile design.

7.5.1 Resistant factors for driven piles in Sand

Table 7.1, 7.1a, 7.1b, 7.1c shows the bias factor and the calibration resistance factor as well as efficiency factor (φ/λ),equivalent factor of safety to ASD and actual mean factor of safety for driven pile in cohesionless soil by different method for calculating the nominal capacity in North, Central and South of Vietnam. The resistant factors by using FORM method and Monte Carlo simulation are almost the same and about 10% higher than FOSM method. Figure 7.5a and 7.5b is an example of the histogram and frequency distribution of bias factor λ1 and an example of resistant factor calibration for 58 cases of concrete piles in Sand using the Nordlund and Thurman method with correlation between the friction angle ϕ and SPT value buy Peck, Hanson and Thurman by using all data for cohesionless soil in Vietnam. The other histograms and frequency distributions of bias factor: λ1 toλ4 and resistant factor calibration: Φ1to Φ4 for All data, North data, and South data can be found in figure F-S1-a to F-S4d in appendix F

Table.7.1 Bias factor λ for driven pile in Cohesionless Soil using Nordlund , Shmertmann SPT and Mayhoft SPT method with Davission's criterion in North, Center and South of Vietnam

	Nordlund		SPT	
	Φ: Peck, Hanson and Thornburn	Φ:Schmertmann	Schmertmann SPT	Mayhoft SPT
	λ1	λ2	λ3	λ4
NP-S1	0.80	0.49	0.89	0.94
NP-S2	0.75	0.46	0.82	0.87
NP-S3	0.83	0.51	0.91	0.97
NP-S4	0.64	0.41	0.82	0.79
NP-S5	0.66	0.42	0.85	0.82
NP-S6	0.61	0.39	0.79	0.76
NP-S7	0.69	0.44	0.88	0.85
NP-S8	0.67	0.43	0.87	0.83
NP-S9	0.67	0.42	0.86	0.83
NP-S10	0.69	0.44	0.89	0.85
NP-S11	0.70	0.44	0.90	0.86
NP-S12	0.63	0.40	0.81	0.78
NP-S13	0.70	0.44	0.89	0.86
NP-S14	0.69	0.44	0.88	0.85

Table 7.1 (cont.)

NP-S15	0.74	0.47	0.95	0.91
NP-S16	0.72	0.46	0.92	0.89
NP-S17	0.73	0.46	0.93	0.90
NP-S18	0.71	0.45	0.91	0.87
NP-S19	0.69	0.44	0.89	0.86
NP-S20	0.57	0.39	0.92	0.94
NP-S21	0.67	0.46	1.09	1.11
NP-S22	0.76	0.51	1.23	1.26
NP-S23	0.51	0.34	0.82	0.84
NP-S24	0.57	0.39	0.93	0.95
NP-S25	0.66	0.45	1.08	1.10
NP-S26	0.84	0.57	1.38	1.40
NP-S27	0.64	0.44	1.05	1.07
NP-S28	0.71	0.49	1.16	1.19
NP-S29	0.63	0.43	1.03	1.05
NP-S30	0.73	0.50	1.19	1.22
NP-S31	0.59	0.40	0.96	0.98
NP-S32	0.61	0.34	1.21	1.42
NP-S33	0.53	0.30	1.04	1.23
NP-S34	0.46	0.26	0.91	1.07
NP-S35	1.11	0.40	1.10	1.03
NP-S36	1.28	0.47	1.27	1.19
NP-S37	1.22	0.44	1.20	1.13
NP-S38	1.16	0.42	1.15	1.08
NP-S39	1.21	0.44	1.19	1.12
NP-S40	0.94	0.68	1.15	1.04
NP-S41	1.13	0.63	0.81	0.65
NP-S42	1.15	0.64	0.82	0.66
NP-S43	1.19	0.66	0.85	0.69
NP-S44	1.50	0.75	1.80	1.94
NP-S45	1.35	0.67	1.62	1.75
NP-S46	1.43	0.72	1.72	1.86
NP-S47	0.78	0.65	1.83	2.14
NP-S48	0.80	0.67	1.88	2.21
NP-S49	0.78	0.65	1.81	2.13
NP-S50	0.70	0.59	1.64	1.93
NP-S51	1.11	0.71	1.05	0.99
NP-S52	1.18	0.75	1.12	1.05
NP-S53	1.26	0.80	1.19	1.12
NP-S54	1.18	0.75	1.12	1.05
SP-S1	0.76	0.58	1.35	1.80
SP-S2	0.84	0.56	1.42	2.09
SP-S3	0.58	0.38	1.10	1.02
SP-S4	0.46	0.30	0.88	0.90

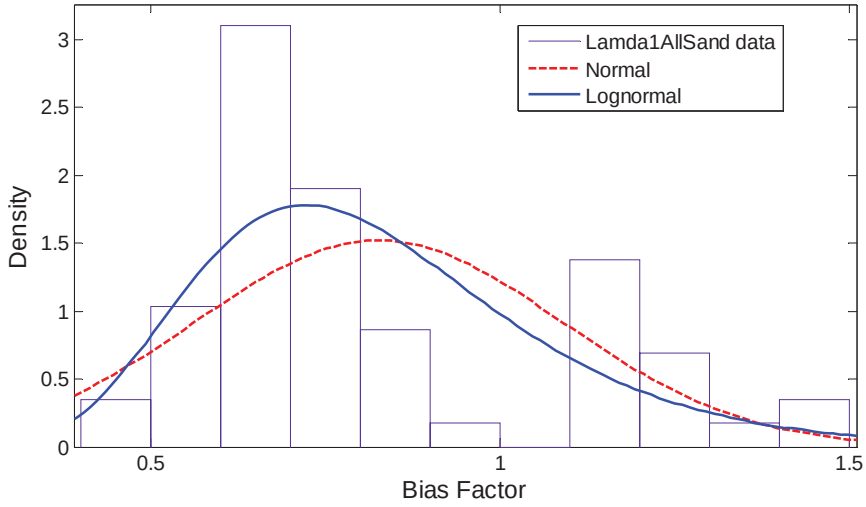


Fig 7.5a Histogram and frequency distribution of bias factor λ1 for 58 cases of concrete piles in Sand using the Nordlund method (ϕ: Peck, Hanson and Thornbum) in Vietnam

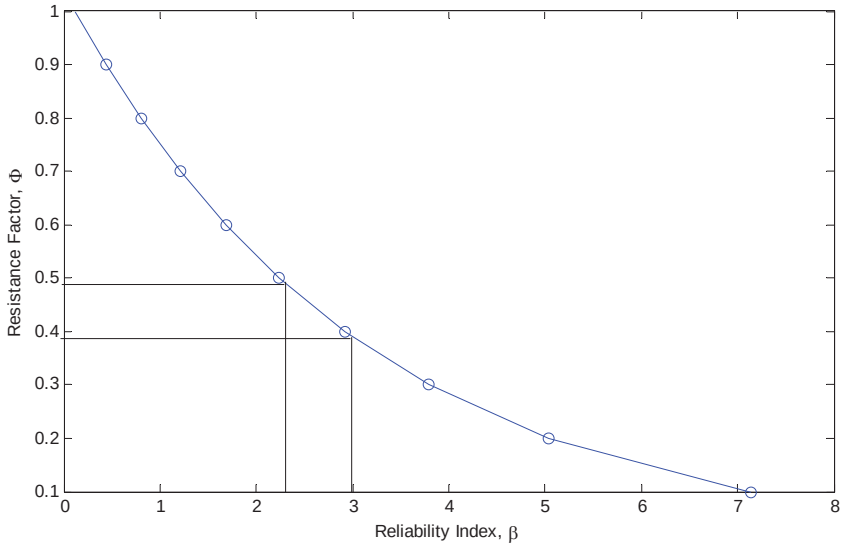


Fig7.5b Resistant factor calibration for 58 cases of concrete piles in Sand using the Nordlund method (ϕ: Peck, Hanson and Thornbum) in Vietnam

Table 7.1a Summary of calibration resistance factor for driven pile using Nordlund ,Shmertmann SPT and Mayhoft SPT method in North, Center and South of Vietnam

		Data from North, Central and South of Vietnam			
		Nordlund-Thurman		SPT	
		ΦPeck, Hanson and Thornburn	Φfrom Schmertmann	Schmertmann SPT	Mayhoft SPT
		λ1	λ2	λ3	λ4
Total	Mean	0.83	0.50	1.10	1.13
58 cases	Stand	0.26	0.13	0.29	0.41
	cov	0.32	0.26	0.27	0.36
β =2.33	FOSM	0.448	0.306	0.662	0.564
	FORM	0.490	0.342	0.732	0.610
	Monte[4]	**0.493**	**0.344**	**0.729**	**0.607**
φ/λ[1]		0.60	0.69	0.66	0.54
FS[2]		2.8	4.0	1.9	2.3
FS x λ[3]		2.3	2.0	2.1	2.6
β =3	FOSM	0.347	0.244	0.527	0.429
	FORM	0.390	0.289	0.598	0.470
	Monte	**0.397**	**0.290**	**0.604**	**0.473**
φ/λ		0.48	0.58	0.55	0.42
FS		3.5	4.7	2.3	2.9
FS x λ		2.9	2.4	2.5	3.3
Good result		good		good	good

1 Efficiency factor 2Equivalent factor of safety to ASD 3 Actual mean factor of safety 4 Monte Carlo simulation

Table 7.1b Summary of calibration resistance factor for driven piles using Nordlund ,Shmertmann SPT and Mayhoft SPT method in North of Vietnam

		Data from North			
		Nordlund-Thurman		SPT	
		ΦPeck, Hanson and Thornburn	Φfrom Schmertmann	Schmertmann SPT	Mayhoft SPT
		λ1	λ2	λ3	λ4
Total	avera	0.84	0.50	1.09	1.11
54 cases	stand	0.27	0.13	0.30	0.39
	cov	0.32	0.26	0.27	0.35
β =2.33	FOSM	0.456	0.309	0.652	0.563
	FORM	0.490	0.342	0.720	0.603
	Monte	**0.489**	**0.343**	**0.712**	**0.601**
φ/λ[1]		0.58	0.68	0.65	0.54
FS[2]		3.0	4.5	2.1	2.4
FS x λ[3]		2.5	2.2	2.3	2.7
β =3	FOSM	0.354	0.247	0.517	0.430
	FORM	0.395	0.285	0.590	0.700
	Monte	**0.394**	**0.287**	**0.586**	**0.466**
φ/λ		0.47	0.57	0.54	0.42
FS		3.9	5.6	2.7	3.2
FS x λ		3.3	2.8	2.9	3.5
Good result		good		good	good

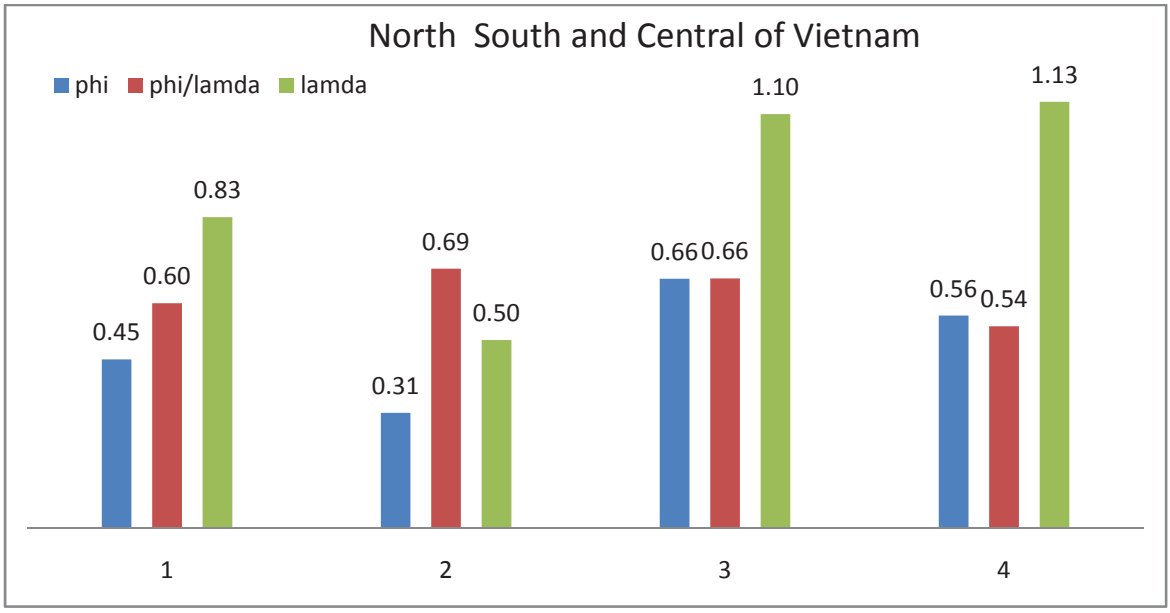


Figure 7.6a Resistance factor, efficiency factor, equivalent factor of safety to ASD for driven pile using Nordlund, Shmertmann SPT and Mayhoft SPT method for Cohesionless Soil in Vietnam with β =2.33

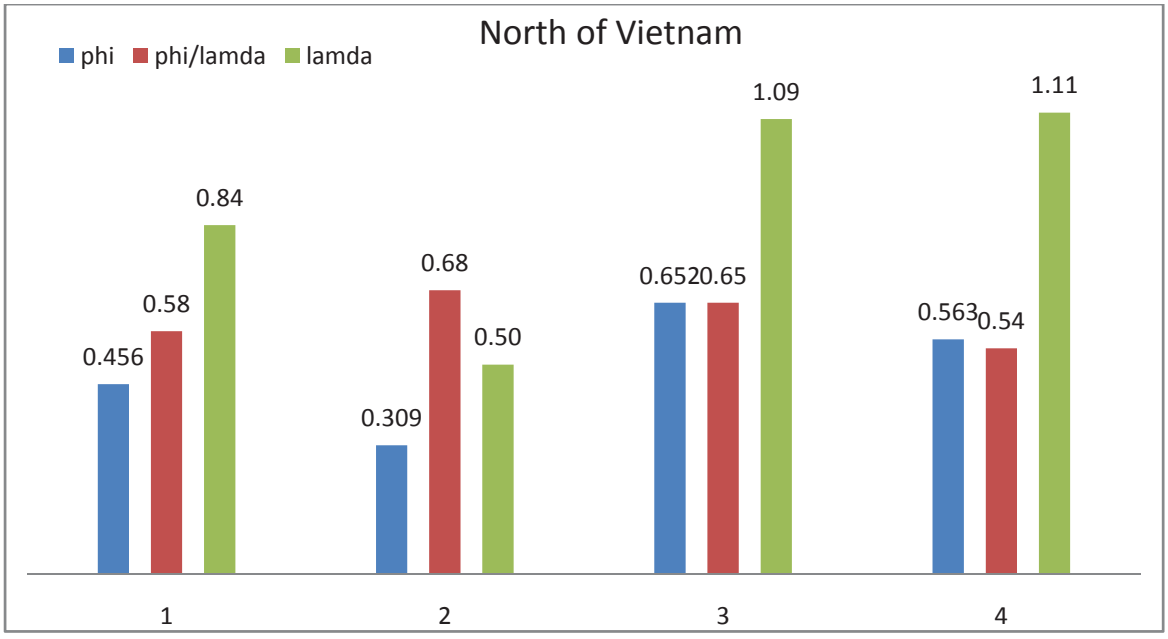


Figure 7.6b Resistance factor, efficiency factor, equivalent factor of safety to ASD for driven pile using Nordlund, Shmertmann SPT and Mayhoft SPT method for Cohesionless Soil in North of Vietnam with β =2.33

7.5.2 Resistant factors for driven piles in Clay

Table 7.2, 7.2a, 7.2b, 7.2c shows the bias factor and the calibration resistance factor as well as efficiency factor (φ/λ), equivalent factor of safety to ASD and actual mean factor of safety for driven pile in Cohesive Soil by different methods for calculating the nominal capacity in North, Central and South of Vietnam. The resistant factors by using FORM method and Monte Carlo simulation are almost the same and about 10% lower than FOSM method.

Figure 7.7a and 7.7b is an example of the histogram and frequency distribution of bias factor $\lambda 1$ and an example of resistant factor calibration for 50 cases of concrete piles in Clay using the α-Tomlinson method with correlation between the undrain shear strength Su and SPT value buy Terzaghi and Peck by using all data for cohesionless soil in Vietnam. The other histograms and frequency distribution of bias factor: $\lambda 1$ to $\lambda 8$ and resistant factor calibration: $\Phi 1$ to $\Phi 8$ corresponding to different methods for all data, north data, and south data are in the figure F-C1-a to F-C8-d in appendix E

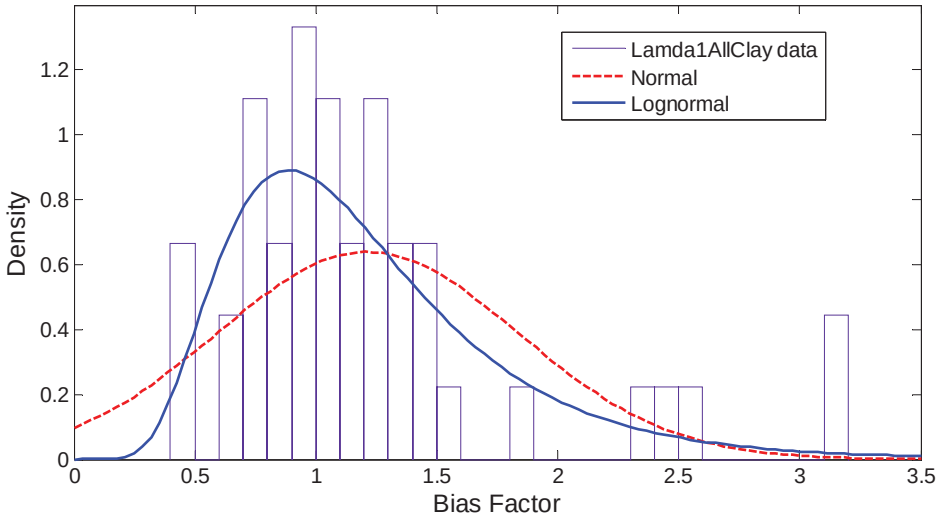


Fig 7.7a Histogram and frequency distribution of bias factor λ1 for 50 cases of concrete piles in Clay using the α-Tomlinson method (Su: Peck) in Vietnam

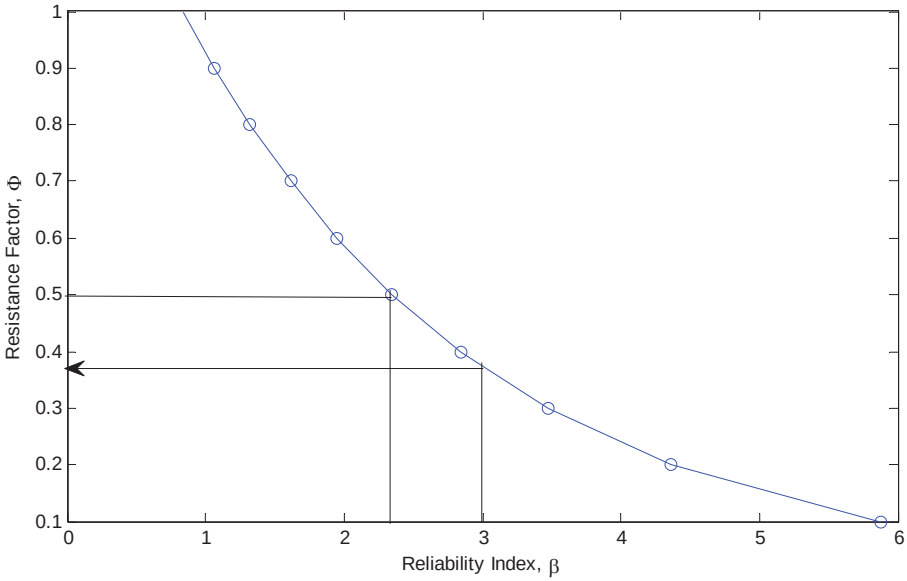


Fig7.7b Resistant factor calibration for 50 cases of concrete piles in Clay using the α-Tomlinson method (Su: Peck) in Vietnam

Table 7.2 Bias factor λ for driven pile in cohesive soil using α-Tomlinson, α-API method, λ method, β-Burland, Shmertmann SPT method with Davission's criterion in North, Center and South of Vietnam

	Data from North, Central and South of Vietnam							
	α-Tomlinson method		α-API method		λ method		β-Burland	Schmertmann SPT
	Su-Terzaghi, Peck	Su-Hara	Su-Terzaghi, Peck	Su-Hara	Su-Terzaghi, Peck	Su-Hara		
	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8
NP-C1	0.80	0.40	1.28	0.62	1.01	0.49	1.33	0.75
NP-C2	1.03	0.52	1.64	0.80	1.30	0.63	1.71	0.97
NP-C3	1.07	0.56	1.38	0.77	1.40	0.76	1.27	0.92
NP-C4	0.98	0.52	1.27	0.71	1.28	0.70	1.16	0.85
NP-C5	1.21	0.64	1.56	0.87	1.58	0.86	1.44	1.05
NP-C6	1.26	0.67	1.63	0.91	1.65	0.90	1.50	1.09
NP-C7	1.00	0.53	1.29	0.72	1.31	0.71	1.18	0.86
NP-C8	1.09	0.80	1.35	0.90	1.48	0.99	1.07	1.21
NP-C9	1.08	0.79	1.34	0.89	1.47	0.98	1.06	1.20
NP-C10	0.82	0.60	1.01	0.68	1.11	0.74	0.80	0.91
NP-C11	0.83	0.61	1.03	0.69	1.13	0.75	0.82	0.92
NP-C12	0.79	0.58	0.98	0.65	1.07	0.71	0.77	0.87
NP-C13	0.85	0.62	1.05	0.70	1.15	0.77	0.83	0.94
NP-C14	1.03	0.77	1.37	0.77	1.21	0.64	1.14	0.93
NP-C15	0.63	0.47	0.83	0.47	0.74	0.39	0.69	0.57
NP-C16	1.03	0.77	1.37	0.78	1.22	0.64	1.14	0.93
NP-C17	1.26	0.85	1.76	0.81	1.35	0.66	1.48	0.97
NP-C18	1.20	0.81	1.68	0.77	1.29	0.63	1.41	0.93
NP-C19	1.01	0.71	1.44	0.69	1.13	0.56	1.33	0.82
NP-C20	0.89	0.62	1.27	0.61	1.00	0.49	1.17	0.72
NP-C21	0.67	0.50	1.36	0.42	0.80	0.44	0.62	0.63
NP-C22	1.03	0.78	2.10	0.65	1.23	0.69	0.96	0.98
NP-C23	0.76	0.74	0.75	0.66	0.79	0.72	0.66	1.06
NM-C24	1.47	0.85	2.17	1.18	1.58	0.87	1.68	1.28
NM-C25	1.47	0.85	2.18	1.18	1.58	0.87	1.69	1.28
NM-C26	1.65	0.95	2.43	1.32	1.76	0.97	1.88	1.43
NM-C27	1.40	0.81	2.07	1.12	1.50	0.83	1.60	1.22
NM-C28	1.10	0.82	1.73	0.54	0.86	0.50	0.85	0.75
NM-C29	0.88	0.66	1.38	0.43	0.69	0.40	0.68	0.60
NM-C30	0.87	0.65	1.37	0.43	0.68	0.40	0.68	0.60
NM-C31	0.92	0.69	1.45	0.46	0.72	0.42	0.72	0.63
NM-C32	0.90	0.67	1.41	0.44	0.70	0.41	0.70	0.61
NM-C33	1.48	0.94	1.86	1.13	1.57	0.91	1.81	0.88
NM-C34	0.46	0.29	0.58	0.35	0.49	0.28	0.56	0.27
NM-C35	1.13	0.71	1.41	0.86	1.19	0.69	1.37	0.67
NM-C36	1.18	0.75	1.48	0.90	1.25	0.73	1.44	0.70
NM-C37	1.16	0.73	1.45	0.89	1.23	0.71	1.41	0.69
NM-C38	1.11	0.70	1.39	0.85	1.17	0.68	1.35	0.66

Table 7.2 (cont.)

CP-C1	2.45	1.33	1.84	1.14	1.64	0.93	1.20	1.07
CP-C2	2.65	1.44	1.99	1.23	1.77	1.01	1.17	1.16
CP-C3	3.16	1.71	2.37	1.46	2.11	1.20	1.35	1.38
CP-C4	2.40	1.30	1.80	1.11	1.60	0.91	1.10	1.05
CP-C5	2.96	1.61	2.22	1.37	1.97	1.12	1.19	1.29
CP-C6	0.82	0.83	1.45	0.77	1.38	0.71	0.71	0.99
CP-C7	1.35	1.37	2.38	1.28	2.28	1.18	1.18	1.63
CP-C8	1.04	1.05	1.83	0.98	1.75	0.90	0.94	1.25
CP-C9	1.29	1.30	2.27	1.21	2.17	1.12	1.13	1.55
CP-C10	1.16	1.17	2.04	1.09	1.95	1.01	1.04	1.39
SP-C1	1.51	0.88	1.68	1.04	1.80	1.08	1.44	1.30
SP-C2	0.71	0.68	0.59	0.43	0.65	0.43	0.45	1.08

Table 7.2a Summary of calibration resistance factor for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Shmertmann SPT method in North, Center and South of Vietnam

		Data from North, South and Central of Vietnam							
		α-Tomlinson method		α-API method		λ method		β-Burland	Schmertmann SPT
		Su-T,P	Su- H	Su-T,P	Su- H	Su-T,P	Su- H		
Total	mean	1.22	0.81	1.55	0.83	1.31	0.74	1.14	0.97
50	stand	0.57	0.30	0.46	0.28	0.42	0.23	0.35	0.28
	cov	0.47	0.37	0.29	0.34	0.32	0.31	0.31	0.29
β =2.33	FOSM	0.481	0.391	0.884	0.435	0.706	0.411	0.625	0.554
	FORM	0.498	0.420	0.975	0.470	0.775	0.450	0.680	0.605
	Monte	**0.508**	**0.417**	**1.008**	**0.478**	**0.782**	**0.455**	**0.706**	**0.599**
φ/λ		0.42	0.51	0.65	0.57	0.60	0.61	0.62	0.62
FS		2.7	3.3	1.4	2.9	1.8	3.0	1.9	2.3
FS x λ		3.3	2.7	2.1	2.4	2.3	2.2	2.2	2.2
β =3	FOSM	0.345	0.295	0.694	0.334	0.547	0.320	0.487	0.435
	FORM	0.375	0.325	0.790	0.378	0.612	0.365	0.550	0.490
	Monte	**0.373**	**0.322**	**0.836**	**0.382**	**0.630**	**0.368**	**0.571**	**0.486**
φ/λ		0.31	0.40	0.54	0.46	0.48	0.50	0.50	0.50
FS		3.7	4.3	1.6	3.6	2.2	3.7	2.4	2.8
FS x λ		4.5	3.5	2.6	3.0	2.9	2.8	2.7	2.7
Good result			good		good		good	good	good

1 Efficiency factor 2Equivalent factor of safety to ASD 3 Actual mean factor of safety 4 Monte Carlo simulation

Table 7.2bSummary of calibration resistance factor for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Shmertmann SPT method in North of Vietnam

		Data from North of Vietnam							
		α-Tomlinson method		α-API method		λ method		β-Burland	Schmertmann SPT
		Su-T,P	Su- H	Su-T,P	Su- H	Su-T,P	Su- H		
Total	mean	1.04	0.68	1.45	0.75	1.18	0.67	1.16	0.88
38	stand	0.25	0.14	0.40	0.23	0.32	0.18	0.38	0.24
	cov	0.24	0.21	0.27	0.31	0.27	0.27	0.33	0.27
β =2.33	FOSM	0.654	0.455	0.859	0.418	0.704	0.398	0.617	0.520
	FORM	0.725	0.510	0.946	0.450	0.775	0.436	0.670	0.575
	Monte	**0.730**	**0.509**	**0.940**	**0.448**	**0.770**	**0.434**	**0.653**	**0.578**
φ/λ		0.70	0.75	0.65	0.59	0.66	0.65	0.56	0.66
FS		2.1	3.0	1.6	3.3	2.0	3.5	2.2	2.6
FS x λ		2.2	2.1	2.3	2.5	2.3	2.3	2.6	2.3
β =3	FOSM	0.526	0.372	0.681	0.326	0.559	0.316	0.476	0.412
	FORM	0.610	0.435	0.775	0.370	0.633	0.362	0.530	0.475
	Monte	**0.610**	**0.438**	**0.777**	**0.363**	**0.634**	**0.355**	**0.521**	**0.474**
φ/λ		0.59	0.64	0.54	0.48	0.54	0.53	0.45	0.54
FS		2.6	3.7	2.0	4.2	2.5	4.4	2.9	3.3
FS x λ		2.7	2.5	2.9	3.2	2.9	2.9	3.3	2.9
Good result		good			good	good		good	good

Table 7.2c Summary of calibration resistance factor for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Shmertmann SPT method in Central of Vietnam

		Data from Central of Vietnam							
		α-Tomlinson method		α-API method		λ method		β Burland	Schmertmann SPT
		Su-T,P	Su- H	Su-T,P	Su- H	Su-T,P	Su- H		
Total	avera	1.93	1.31	2.02	1.17	1.86	1.01	1.10	1.28
11	stand	0.88	0.26	0.30	0.20	0.28	0.15	0.17	0.21
	cov	0.46	0.19	0.15	0.17	0.15	0.15	0.16	0.17
β =2.33	FOSM	0.779	0.901	1.491	0.834	1.367	0.743	0.801	0.916
	FORM	0.830	1.100	1.750	0.965	1.590	0.860	0.925	1.035
	Monte	**0.879**	**1.023**	**1.754**	**0.966**	**1.602**	**0.872**	**0.937**	**1.030**
φ/λ		0.46	0.78	0.87	0.83	0.86	0.87	0.85	0.81
FS		1.8	1.5	0.9	1.6	1.0	1.9	1.7	1.5
FS x λ		3.4	2.0	1.9	1.9	1.9	1.9	1.9	1.9
β =3	FOSM	0.563	0.742	1.250	0.694	1.145	0.623	0.669	0.762
	FORM	0.610	0.880	1.550	0.840	1.400	0.750	0.820	0.920
	Monte	**0.650**	**0.882**	**1.557**	**0.851**	**1.422**	**0.778**	**0.825**	**0.901**
φ/λ		0.34	0.67	0.77	0.73	0.76	0.77	0.75	0.71
FS		2.4	1.9	1.1	2.0	1.2	2.2	2.1	1.8
FS x λ		4.7	2.4	2.2	2.3	2.2	2.2	2.3	2.3
Good result			good		good		good	good	good

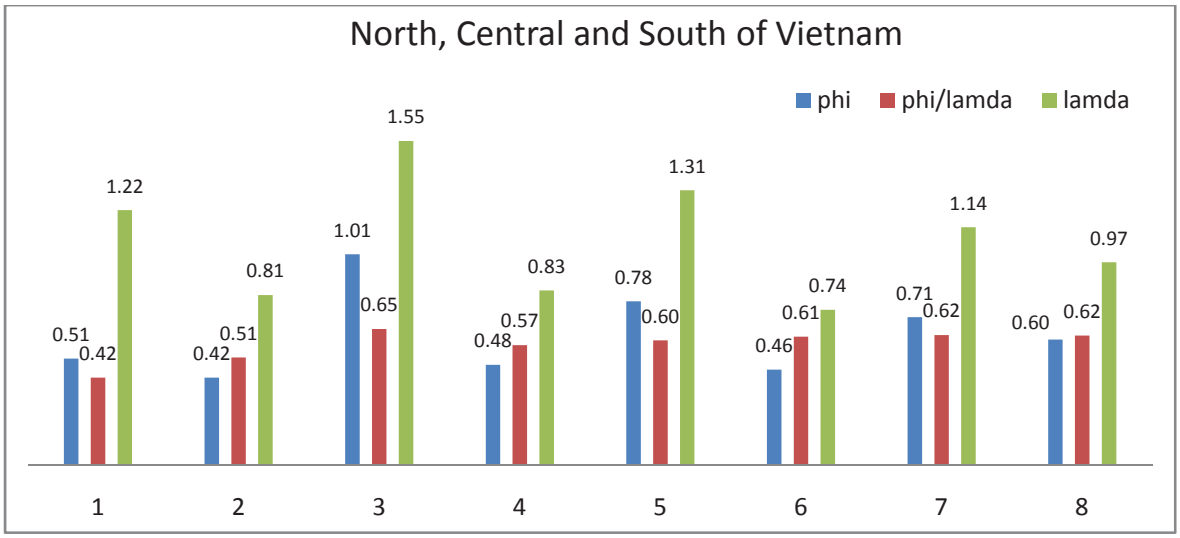


Figure 7.8a Resistance factor, efficiency factor, equivalent factor of safety to ASD for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Shmertmann SPT method for Cohesive Soil in Vietnam with β =2.33

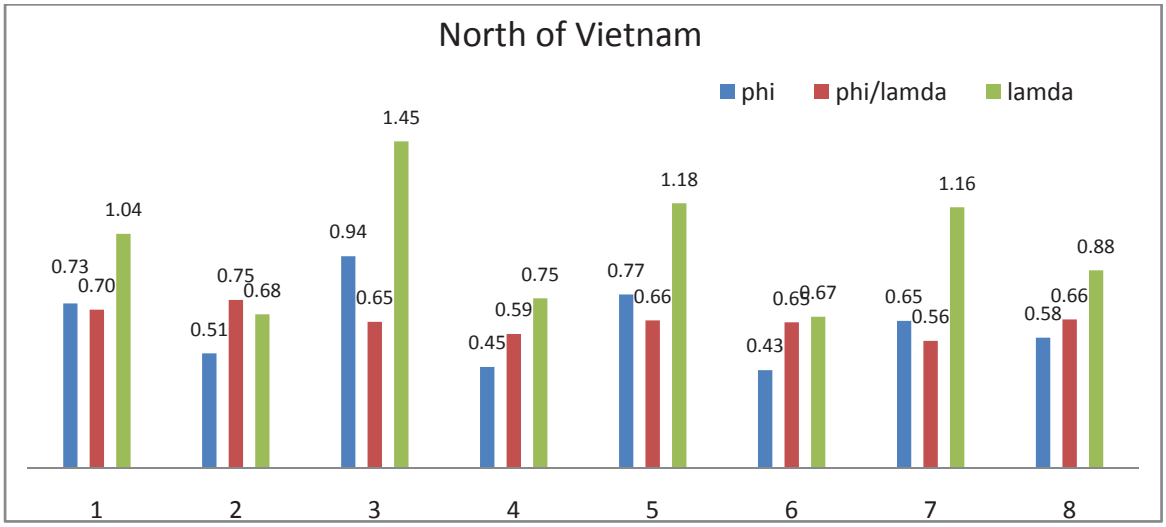


Figure 7.8b Resistance factor, efficiency factor, equivalent factor of safety to ASD for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Shmertmann SPT method for Cohesive Soil in North of Vietnam with β =2.33

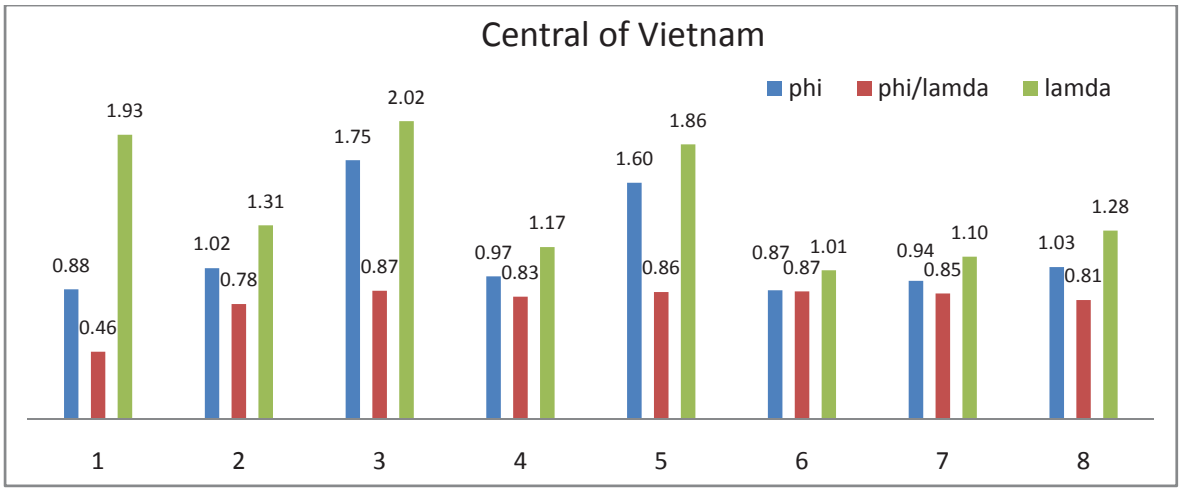


Figure 7.8c Resistance factor, efficiency factor, equivalent factor of safety to ASD for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Shmertmann SPT method for Cohesive Soil in Central of Vietnam with β =2.33

7.5.3 Resistant factors for driven piles in Mixed Soil

Table 7.3, 7.3a, 7.3b, 7.3c, 7.3d shows the bias factor and the calibration resistance factor as well as efficiency factor (φ/λ), equivalent factor of safety to ASD and actual mean factor of safety for driven pile in Mixed soil by different methods for calculating the nominal capacity in North, Central and South of Vietnam. The resistant factors by using FORM method and Monte Carlo simulation are almost the same and about 10% lower than FOSM method. Figure 7.9a and 7.9b is an example of the histogram and frequency distribution of bias factor λ1 and an example of resistant factor calibration for 165 cases of concrete piles in mixed soil. The other histogram and frequency distribution of bias factor fromλ1 toλ15 and resistant factor calibration from Φ1 to Φ15 for different method and with all data, north data, and south data are in the figure F-M1-a to F-M8-d in appendix F

Table 7.3 Summary of calibration resistance factor for driven pile using α-Tomlinson, α-API method, λ method, β-Burland,Nordlund-Thurman, Shmertmann SPT method in North, Center and South of Vietnam

	Data from North, Central and South of Vietnam														
	Φ from Peck, Hanson and Thornburn							Φ from Schmertmann							
	α-Tomlinson &Nordlund		α-API &Nordlund		λ &Nordlund		β Burland/ Nordlund	α-Tomlinson &Nordlund		α-API &Nordlund		λ &Nordlund		β Burland& Nordlund	Schmertmann SPT
	Su-T,P	Su- H	Su-T,P	Su- H	Su-T,P	Su- H		Su-T,P	Su- H	Su-T,P	Su- H	Su-T,P	Su- H		
	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8	λ9	λ10	λ11	λ12	λ11	λ14	λ15
NP-M1	218.3	236.4	178.9	267.2	180.5	269.7	203.6	271.2	289.3	231.8	320.1	144.0	322.6	256.5	153.7
NP-M2	241.3	261.3	197.7	295.3	199.5	298.0	225.0	299.8	319.8	256.2	353.8	159.2	356.5	283.5	169.9
NP-M3	146.9	190.9	138.2	154.7	138.6	157.1	137.6	115.8	320.2	267.5	284.0	267.9	286.4	266.9	142.1
NP-M4	154.6	201.0	145.5	162.8	145.9	165.4	144.9	121.9	337.1	281.6	298.9	282.0	301.5	280.9	149.6
NP-M5	162.3	211.0	152.8	171.0	153.2	173.7	152.1	128.0	353.9	295.6	313.9	296.1	316.5	295.0	157.1
NP-M6	213.1	361.2	210.7	278.1	201.1	258.3	260.6	314.0	462.1	311.7	379.0	302.1	359.2	361.5	162.5
NP-M7	207.5	351.7	205.2	270.7	195.9	251.5	253.7	305.8	450.0	303.5	369.0	294.1	349.7	352.0	158.2
NP-M8	224.3	380.2	221.8	292.7	211.7	271.9	274.3	330.6	486.5	328.1	398.9	318.0	378.1	380.5	171.1
NP-M9	229.9	389.7	227.4	300.0	217.0	278.7	281.1	338.8	498.6	336.3	408.9	325.9	387.6	390.0	175.4
NP-M11	144.6	153.0	129.3	149.0	127.6	149.1	134.8	227.9	236.4	212.6	232.3	211.0	232.4	218.2	119.9
NP-M12	148.5	157.1	132.8	153.0	131.1	153.1	138.5	234.1	242.7	218.4	238.6	216.7	238.7	224.1	123.1
NP-M13	152.4	161.3	136.3	157.0	134.5	157.1	142.1	240.3	249.1	224.1	244.9	222.4	245.0	230.0	126.4
NP-M14	156.3	165.4	139.7	161.0	138.0	161.1	145.7	246.4	255.5	229.9	251.2	228.1	251.3	235.9	129.6
NP-M15	160.2	169.5	143.2	165.1	141.4	165.2	149.4	252.6	261.9	235.6	257.4	233.8	257.6	241.8	132.8
NP-M16	164.1	173.7	146.7	169.1	144.9	169.2	153.0	258.7	268.3	241.4	263.7	239.5	263.8	247.7	136.1
NP-M17	168.0	177.8	150.2	173.1	148.3	173.2	156.7	264.9	274.7	247.1	270.0	245.2	270.1	253.6	139.3
NP-M18	89.5	102.2	71.8	93.5	65.7	86.1	78.6	124.7	137.4	106.9	128.6	105.9	121.2	103.4	82.9
NP-M19	94.5	107.8	75.8	98.7	69.4	90.8	83.0	131.6	145.0	112.9	135.8	111.8	128.0	109.2	87.5
NP-M20	99.5	113.5	79.7	103.8	73.1	95.6	87.3	138.6	152.6	118.8	142.9	117.7	134.7	114.9	92.1
NP-M21	104.5	119.2	83.7	109.0	76.7	100.4	91.7	145.5	160.2	124.8	150.1	123.6	141.4	120.7	96.7
NP-M22	109.4	124.9	87.7	114.2	80.4	105.2	96.1	152.4	167.9	130.7	157.2	129.5	148.2	126.4	101.3
NP-M23	112.4	128.3	90.1	117.3	82.6	108.1	98.7	156.6	172.5	134.3	161.5	133.0	152.2	129.9	104.0
NP-M24	33.9	42.2	28.5	33.3	29.3	34.8	27.6	42.6	50.9	37.2	42.0	34.0	43.5	36.3	38.5
NP-M25	30.6	38.0	25.6	30.0	26.4	31.4	24.9	38.4	45.8	33.4	37.8	30.6	39.2	32.7	34.6
NP-M26	182.1	178.6	128.7	231.1	130.9	240.7	137.3	182.1	178.6	128.7	231.1	130.9	240.7	137.3	191.7
NP-M27	192.2	188.5	135.9	243.9	138.2	254.0	144.9	192.2	188.5	135.9	243.9	138.2	254.0	144.9	202.4
NP-M28	202.3	198.4	143.0	256.8	145.5	267.4	152.5	202.3	198.4	143.0	256.8	145.5	267.4	152.5	213.1
NP-M29	212.4	208.3	150.2	269.6	152.7	280.8	160.1	212.4	208.3	150.2	269.6	152.7	280.8	160.1	223.7

Table 7.3(cont.)

NP-M30	222.5	218.3	157.3	282.4	160.0	294.1	167.8	222.5	218.3	157.3	282.4	160.0	294.1	167.8	234.4
NP-M31	330.8	374.4	314.5	340.5	312.4	338.0	320.0	381.1	424.7	364.8	390.8	362.7	388.3	370.2	183.0
NP-M32	323.0	365.5	307.0	332.4	305.0	330.0	312.3	372.0	414.6	356.1	381.5	354.0	379.0	361.4	178.6
NP-M33	315.1	356.6	299.6	324.3	297.5	321.9	304.7	362.9	404.4	347.4	372.2	345.4	369.8	352.6	174.3
NP-M34	307.2	347.7	292.1	316.2	290.1	313.9	297.1	353.9	394.3	338.7	362.9	336.7	360.5	343.8	169.9
NP-M35	299.3	338.8	284.6	308.1	282.7	305.8	289.5	344.8	384.2	330.0	353.6	328.1	351.3	334.9	165.6
NP-M36	291.5	329.8	277.1	300.0	275.2	297.8	281.9	335.7	374.1	321.4	344.3	319.5	342.0	326.1	161.2
NP-M41	685.6	681.7	680.3	707.8	668.6	691.2	689.6	1096.1	1092.3	1090.9	1118.4	1079.2	1101.7	1100.2	305.9
NP-M42	623.2	619.8	618.5	643.4	607.8	628.3	626.9	996.5	993.0	991.7	1016.7	981.1	1001.6	1000.2	278.1
NP-M43	560.9	557.8	556.6	579.1	547.0	565.5	564.2	896.8	893.7	892.6	915.0	883.0	901.4	900.2	250.3
NP-M44	529.7	526.8	525.7	546.9	516.6	534.1	532.9	847.0	844.1	843.0	864.2	833.9	851.4	850.2	236.4
NP-M45	498.6	495.8	494.8	514.7	486.3	502.7	501.5	797.2	794.4	793.4	813.4	784.9	801.3	800.1	222.5
NP-M46	64.9	77.5	49.6	67.3	54.7	79.9	51.0	94.8	107.4	79.4	97.2	84.6	109.8	80.9	57.2
NP-M47	66.6	79.6	50.9	69.1	56.2	82.0	52.4	97.3	110.3	81.6	99.8	86.9	112.7	83.1	58.8
NP-M48	68.4	81.7	52.3	70.9	57.6	84.2	53.8	99.9	113.2	83.7	102.4	89.1	115.7	85.3	60.3
NP-M49	70.1	83.8	53.6	72.7	59.1	86.4	55.2	102.4	116.1	85.9	105.0	91.4	118.7	87.5	61.8
NP-M50	71.9	85.8	54.9	74.6	60.6	88.5	56.5	105.0	119.0	88.0	107.7	93.7	121.6	89.6	63.4
NP-M51	73.6	87.9	56.3	76.4	62.1	90.7	57.9	107.6	121.9	90.2	110.3	96.0	124.6	91.8	64.9
NP-M52	75.4	90.0	57.6	78.2	63.6	92.8	59.3	110.1	124.8	92.3	112.9	98.3	127.6	94.0	66.5
NP-M53	55.4	79.1	46.5	56.4	46.9	59.1	44.7	73.8	76.2	64.8	74.7	65.3	77.5	63.1	45.2
NP-M54	110.8	169.8	98.3	125.2	100.6	128.7	111.4	146.6	205.7	134.1	161.1	136.5	164.5	147.3	86.1
NP-M55	120.0	179.4	107.2	134.2	101.5	122.5	119.7	147.6	207.0	134.8	161.8	129.1	150.1	147.3	93.2
NP-M56	231.2	262.7	205.9	232.3	206.5	238.7	201.6	266.9	298.5	241.7	268.1	242.2	274.5	237.3	130.2
NP-M57	211.3	229.8	192.9	208.2	193.9	213.6	186.1	268.5	286.9	250.1	265.4	251.0	270.8	243.3	134.0
NP-M58	56.5	56.3	50.3	58.2	50.7	59.5	50.9	104.2	103.9	98.0	105.9	98.4	107.1	98.5	75.1
NP-M59	62.8	62.5	55.9	64.7	56.3	66.1	56.5	115.7	115.5	108.8	117.6	109.3	119.0	109.5	83.4
NP-M60	69.1	68.8	61.5	71.1	62.0	72.7	62.2	127.3	127.0	119.7	129.4	120.2	130.9	120.4	91.7
NP-M61	150.6	150.6	150.6	150.6	150.6	150.6	150.6	198.4	198.4	198.4	198.4	198.4	198.4	198.4	77.5
NP-M62	136.9	136.9	136.9	136.9	136.9	136.9	136.9	180.4	180.4	180.4	180.4	180.4	180.4	180.4	70.5
NP-M63	41.9	45.7	36.5	41.2	38.0	45.8	34.7	39.8	43.6	34.4	39.1	35.9	43.7	32.6	37.1
NP-M64	38.1	41.5	33.2	37.4	34.5	41.6	31.6	36.2	39.6	31.3	35.5	32.6	39.7	29.7	33.8
NP-M65	34.3	37.4	29.9	33.7	31.1	37.4	28.4	32.6	35.7	28.2	32.0	29.4	35.7	26.7	30.4
NP-M66	31.9	31.9	31.9	31.9	31.9	31.9	31.9	43.3	43.3	43.3	43.3	43.3	43.3	43.3	26.1
NP-M67	35.3	35.3	35.3	35.3	35.3	35.3	35.3	47.9	47.9	47.9	47.9	47.9	47.9	47.9	28.8
NP-M68	113.1	113.1	113.1	113.1	113.1	113.1	113.1	152.7	152.7	152.7	152.7	152.7	152.7	152.7	69.7
NP-M69	119.1	119.1	119.1	119.1	119.1	119.1	119.1	160.7	160.7	160.7	160.7	160.7	160.7	160.7	73.3

Table 7.3 (cont.)

NP-M70	125.0	125.0	125.0	125.0	125.0	125.0	125.0	168.8	168.8	168.8	168.8	168.8	168.8	168.8	77.0
NP-M71	117.8	191.3	88.2	88.2	68.1	113.1	111.0	114.5	183.0	84.9	152.7	64.8	104.8	107.7	92.4
NP-M72	120.9	196.3	90.5	90.6	69.8	116.1	113.9	117.5	187.8	87.1	156.7	66.5	107.6	110.6	94.9
NP-M73	124.0	201.3	92.8	92.9	71.6	119.0	116.9	120.5	192.6	89.4	160.7	68.2	110.3	113.4	97.3
NP-M74	130.2	211.4	97.4	97.5	75.2	125.0	122.7	126.6	202.2	93.8	168.8	71.6	115.8	119.1	102.2
NP-M75	300.3	288.2	287.9	364.7	256.7	313.9	384.8	363.3	351.2	350.9	427.7	319.7	376.9	447.8	178.3
NP-M76	316.1	303.4	303.1	383.9	270.2	330.4	405.0	382.4	369.7	369.4	450.2	336.5	396.7	471.3	187.7
NP-M77	331.9	318.6	318.2	403.1	283.7	347.0	425.3	401.5	388.2	387.9	472.7	353.3	416.6	494.9	197.0
NM-M78	133.5	221.3	162.1	218.3	168.6	232.5	145.7	138.6	138.6	138.6	138.6	138.6	138.6	138.6	174.9
NP-M81	78.2	87.8	90.7	111.5	82.9	104.1	96.2	142.4	152.0	155.0	175.7	147.2	168.3	160.5	58.0
NP-M82	70.7	79.4	82.1	100.9	75.0	94.2	87.1	128.8	137.5	140.2	159.0	133.1	152.3	145.2	52.5
NP-M83	52.2	53.3	43.4	55.1	49.5	68.2	40.5	85.4	86.5	76.6	88.3	82.7	101.4	73.7	63.6
NP-M84	47.2	48.2	39.3	49.8	44.8	61.7	36.6	77.3	78.3	69.3	79.9	74.9	91.8	66.7	57.6
NP-M85	90.4	93.8	89.0	97.6	85.8	93.5	94.0	257.0	260.4	255.6	264.2	252.3	260.1	260.6	55.2
NP-M86	81.8	84.8	80.5	88.3	77.6	84.6	85.1	232.5	235.6	231.3	239.1	228.3	235.3	235.8	50.0
NP-M87	69.1	85.2	56.5	74.4	59.2	77.4	61.3	67.1	83.1	54.5	72.4	57.2	75.3	59.3	68.5
NP-M88	76.4	94.1	62.4	82.2	65.4	85.5	67.7	74.1	91.9	60.2	80.0	63.2	83.3	65.5	75.7
NP-M89	25.7	27.8	25.7	25.7	25.7	25.7	25.7	50.4	52.5	50.4	50.4	50.4	50.4	50.4	28.6
NP-M90	28.4	30.7	28.4	28.4	28.4	28.4	28.4	55.7	58.0	55.7	55.7	55.7	55.7	55.7	31.6
NP-M91	98.5	107.5	99.7	129.1	90.6	109.1	127.7	129.8	138.8	131.1	160.4	121.9	140.4	159.0	63.3
NP-M92	103.6	113.1	105.0	135.9	95.4	114.8	134.4	136.6	146.1	138.0	168.9	128.3	147.8	167.4	66.7
NP-M93	108.8	118.8	110.2	142.7	100.1	120.6	141.2	143.4	153.4	144.9	177.3	134.8	155.2	175.8	70.0
NP-M94	69.3	65.3	50.3	67.5	59.1	87.9	48.9	123.9	119.8	104.9	122.1	113.7	142.4	103.5	68.9
NP-M95	73.0	68.7	53.0	71.1	62.2	92.5	51.5	130.4	126.1	110.4	128.5	119.6	149.9	108.9	72.5
NP-M96	76.6	72.1	55.6	74.7	65.3	97.1	54.1	136.9	132.4	115.9	134.9	125.6	157.4	114.3	76.1
NP-M97	52.7	69.4	44.3	54.2	46.2	59.8	42.7	79.6	96.2	71.2	81.1	73.1	86.6	69.5	44.9
NP-M98	58.2	76.7	49.0	59.9	51.1	66.1	47.2	87.9	106.4	78.7	89.6	80.8	95.8	76.9	49.6
NP-M99	214.6	523.3	226.3	336.7	181.5	285.2	377.7	207.5	504.3	219.3	317.7	174.4	266.1	370.6	178.0
NP-M102	198.9	485.3	207.9	311.4	166.2	263.0	343.3	191.9	466.3	200.8	292.4	159.2	244.0	336.3	165.2
NP-M103	43.1	47.9	42.0	42.0	42.6	67.9	48.1	48.3	53.2	47.2	67.4	47.8	67.9	53.3	61.1
NP-M104	47.9	53.3	46.7	46.7	47.3	75.5	53.4	53.7	59.1	52.5	74.9	53.1	75.5	59.2	67.9
NP-M105	52.6	58.6	51.3	51.3	52.0	83.0	58.7	59.0	65.0	57.7	82.4	58.4	83.0	65.1	74.7
NP-M106	247.4	280.3	251.9	290.0	238.4	265.4	311.0	331.3	364.1	335.8	373.9	322.3	349.3	394.9	137.3
NP-M107	222.9	251.1	229.2	265.8	216.0	241.5	289.3	333.5	361.7	339.8	376.4	326.6	352.1	399.9	135.3
NP-M108	252.5	278.9	258.5	295.2	244.3	270.2	318.4	361.4	387.9	367.4	404.1	353.2	379.1	427.3	129.4
CP-M1	170.8	225.2	154.4	242.7	159.2	254.1	169.2	174.2	192.3	174.2	192.3	192.3	174.2	174.2	226.1

Table 7.3 (cont.)

CP-M2	179.7	237.0	162.6	255.4	167.6	267.4	178.1	183.4	202.4	183.4	202.4	202.4	183.4	183.4	238.0
CP-M3	188.7	248.9	170.7	268.2	176.0	280.8	187.0	192.6	212.6	192.6	212.6	212.6	192.6	192.6	249.9
CP-M4	195.3	259.1	177.0	278.8	182.4	291.6	193.6	199.2	222.1	199.2	222.1	222.1	199.2	199.2	263.6
CP-M5	215.9	286.4	195.6	308.1	201.6	322.3	214.0	220.2	245.5	220.2	245.5	245.5	220.2	220.2	291.3
CP-M6	248.4	329.4	231.7	361.7	237.6	379.0	263.9	252.5	279.3	252.5	279.3	279.3	252.5	252.5	330.7
CP-M7	303.6	402.6	283.2	442.1	290.4	463.2	322.5	308.6	341.3	308.6	341.3	341.3	308.6	308.6	404.2
CP-M8	248.4	329.4	231.7	361.7	237.6	379.0	263.9	252.5	279.3	252.5	279.3	279.3	252.5	252.5	330.7
CP-M9	276.0	366.0	257.4	401.9	264.0	421.1	293.2	280.5	310.3	280.5	310.3	310.3	280.5	280.5	367.4
CP-M10	289.8	384.3	270.3	422.0	277.2	442.1	307.8	294.6	325.8	294.6	325.8	325.8	294.6	294.6	385.8
CP-M11	220.8	292.8	205.9	321.5	211.2	336.9	234.5	224.4	248.2	224.4	248.2	248.2	224.4	224.4	293.9
CP-M12	303.6	402.6	283.2	442.1	290.4	463.2	322.5	308.6	341.3	308.6	341.3	341.3	308.6	308.6	404.2
CP-M13	289.8	384.3	270.3	422.0	277.2	442.1	307.8	294.6	325.8	294.6	325.8	325.8	294.6	294.6	385.8
CP-M14	276.0	366.0	257.4	401.9	264.0	421.1	293.2	280.5	310.3	280.5	310.3	310.3	280.5	280.5	367.4
CP-M15	303.6	402.6	283.2	442.1	290.4	463.2	322.5	308.6	341.3	308.6	341.3	341.3	308.6	308.6	404.2
CP-M16	303.6	402.6	283.2	442.1	290.4	463.2	322.5	308.6	341.3	308.6	341.3	341.3	308.6	308.6	404.2
CP-M17	248.4	329.4	231.7	361.7	237.6	379.0	263.9	252.5	279.3	252.5	279.3	279.3	252.5	252.5	330.7
CP-M20	257.6	370.9	207.5	303.5	220.9	309.0	250.4	299.2	412.6	249.1	345.1	262.5	246.9	292.0	279.2
CP-M21	263.4	379.4	212.2	310.4	225.9	316.0	256.1	306.0	421.9	254.8	352.9	268.5	252.5	298.7	285.6
CP-M22	269.3	387.8	216.9	317.3	230.9	323.0	261.8	312.8	431.3	260.5	360.8	274.4	258.1	305.3	291.9
CP-M23	275.1	396.2	221.7	324.2	235.9	330.1	267.5	319.6	440.7	266.1	368.6	280.4	263.7	312.0	298.2
CP-M24	281.0	404.7	226.4	331.0	240.9	337.1	273.2	326.4	450.1	271.8	376.5	286.3	269.3	318.6	304.6
CP-M25	286.8	413.1	231.1	337.9	245.9	344.1	278.9	333.2	459.5	277.4	384.3	292.3	274.9	325.2	310.9
CP-M26	292.7	421.5	235.8	344.8	251.0	351.1	284.6	340.0	468.8	283.1	392.2	298.3	280.5	331.9	317.3
CP-M27	298.6	429.9	240.5	351.7	256.0	358.2	290.2	346.8	478.2	288.8	400.0	304.2	286.1	338.5	323.6
CP-M28	304.4	438.4	245.2	358.6	261.0	365.2	295.9	353.6	487.6	294.4	407.8	310.2	291.8	345.1	330.0
CP-M29	310.3	446.8	249.9	365.5	266.0	372.2	301.6	360.4	497.0	300.1	415.7	316.2	297.4	351.8	336.3
CP-M30	316.1	455.2	254.7	372.4	271.0	379.2	307.3	367.2	506.3	305.8	423.5	322.1	303.0	358.4	342.7
CP-M31	322.0	463.7	259.4	379.3	276.1	386.3	313.0	374.0	515.7	311.4	431.4	328.1	308.6	365.1	349.0
CP-M32	327.8	472.1	264.1	386.2	281.1	393.3	318.7	380.8	525.1	317.1	439.2	334.1	314.2	371.7	355.4
CP-M33	333.7	480.5	268.8	393.1	286.1	400.3	324.4	387.6	534.5	322.7	447.1	340.0	319.8	378.3	361.7
CP-M34	95.1	126.9	81.3	106.0	81.7	108.1	84.1	85.9	117.7	72.1	96.8	72.5	98.9	74.9	95.3
CP-M35	98.2	130.9	83.9	109.4	84.3	111.6	86.8	88.6	121.4	74.4	99.9	74.8	102.1	77.3	98.4
CP-M36	101.2	135.0	86.5	112.8	86.9	115.0	89.5	91.4	125.2	76.7	103.0	77.1	105.2	79.7	101.4
CP-M37	103.2	137.7	88.3	115.1	88.6	117.3	91.3	93.2	127.7	78.2	105.1	78.6	107.3	81.3	103.4
CP-M38	105.2	140.4	90.0	117.3	90.4	119.6	93.1	95.0	130.2	79.8	107.1	80.2	109.4	82.9	105.5
CP-M39	107.3	143.1	91.7	119.6	92.1	121.9	94.9	96.9	132.7	81.3	109.2	81.7	111.5	84.5	107.5

Table 7.3 (cont.)

CP-M40	73.7	123.1	62.0	99.0	57.5	95.2	78.4	78.7	128.1	67.0	104.0	62.5	100.2	83.4	72.3
CP-M41	77.7	130.0	65.4	104.5	60.7	100.5	82.7	83.0	135.2	70.7	109.8	66.0	105.8	88.0	76.3
CP-M42	81.8	136.8	68.9	110.0	63.9	105.8	87.1	87.4	142.4	74.4	115.6	69.4	111.4	92.6	80.3
CP-M43	90.0	150.5	75.8	121.0	70.3	116.4	95.8	96.1	156.6	81.9	127.1	76.4	122.5	101.9	88.3
SP-M1	165.5	165.5	165.5	165.5	165.5	165.5	165.5	296.2	296.2	296.2	296.2	296.2	296.2	296.2	102.8
SP-M2	169.1	169.1	169.1	169.1	169.1	169.1	169.1	302.7	302.7	302.7	302.7	302.7	302.7	302.7	105.0
SP-M3	172.7	172.7	172.7	172.7	172.7	172.7	172.7	309.1	309.1	309.1	309.1	309.1	309.1	309.1	107.2
SP-M4	176.3	176.3	176.3	176.3	176.3	176.3	176.3	315.5	315.5	315.5	315.5	315.5	315.5	315.5	109.5
SP-M5	179.9	179.9	179.9	179.9	179.9	179.9	179.9	322.0	322.0	322.0	322.0	322.0	322.0	322.0	111.7
SP-M6	183.5	183.5	183.5	183.5	183.5	183.5	183.5	328.4	328.4	328.4	328.4	328.4	328.4	328.4	113.9
SP-M7	187.1	187.1	187.1	187.1	187.1	187.1	187.1	334.9	334.9	334.9	334.9	334.9	334.9	334.9	116.2
SP-M8	190.7	190.7	190.7	190.7	190.7	190.7	190.7	341.3	341.3	341.3	341.3	341.3	341.3	341.3	118.4
SP-M9	194.3	194.3	194.3	194.3	194.3	194.3	194.3	347.7	347.7	347.7	347.7	347.7	347.7	347.7	120.7
SP-M10	62.1	71.4	57.3	80.0	61.9	92.6	54.1	66.9	76.2	62.0	84.8	66.6	97.3	58.9	75.4
SP-M11	63.4	72.9	58.5	81.7	63.2	94.5	55.3	68.3	77.8	63.4	86.6	68.0	99.4	60.1	77.0
SP-M12	64.8	74.4	59.7	83.4	64.5	96.5	56.4	69.7	79.4	64.7	88.4	69.5	101.5	61.4	78.6
SP-M14	67.4	77.5	62.2	86.8	67.1	100.4	58.7	72.6	82.6	67.3	92.0	72.3	105.6	63.9	81.8
SP-M16	70.1	80.5	64.6	90.2	69.8	104.4	61.0	75.4	85.9	70.0	95.6	75.1	109.7	66.4	85.0
SP-M17	570.2	568.9	648.7	757.4	587.6	674.4	788.2	653.9	652.6	732.4	841.1	671.3	758.1	871.9	348.3
SP-M18	630.3	628.7	717.0	837.2	649.4	745.3	871.2	722.8	721.2	809.5	929.7	741.9	837.9	963.7	385.0
SP-M19	78.3	111.2	63.5	78.4	68.5	90.7	61.6	104.0	136.9	89.2	104.1	94.2	116.4	87.3	73.8
SP-M20	82.6	117.4	67.1	82.7	72.3	95.7	65.0	109.8	144.6	94.2	109.9	99.4	122.8	92.2	77.9
SP-M21	87.0	123.6	70.6	87.1	76.1	100.7	68.5	115.5	152.2	99.2	115.6	104.7	129.3	97.0	82.0
SP-M22	95.7	136.0	77.7	95.8	83.7	110.8	75.3	127.1	167.4	109.1	127.2	115.1	142.2	106.7	90.2
SP-M23	232.5	266.0	243.9	275.4	230.3	254.2	266.6	343.0	376.4	354.3	385.8	340.7	364.6	377.0	165.0
SP-M24	271.3	273.0	274.5	296.3	265.2	281.7	295.2	368.5	370.2	371.7	393.5	362.4	378.9	392.4	141.8
SP-M25	134.4	177.1	166.9	249.1	163.4	219.4	189.5	166.1	189.1	178.9	261.2	175.5	231.5	201.5	189.5
SP-M26	293.1	303.1	291.4	296.1	289.6	294.0	291.8	454.9	465.0	453.2	457.9	451.5	455.9	453.7	181.8
SP-M27	262.7	263.1	265.5	279.5	258.9	270.6	272.5	369.0	369.4	371.8	385.8	365.2	376.8	378.8	89.0
SP-M28	349.4	364.2	349.4	370.1	333.2	353.5	369.0	482.1	497.0	482.1	502.9	465.9	486.3	501.8	173.2

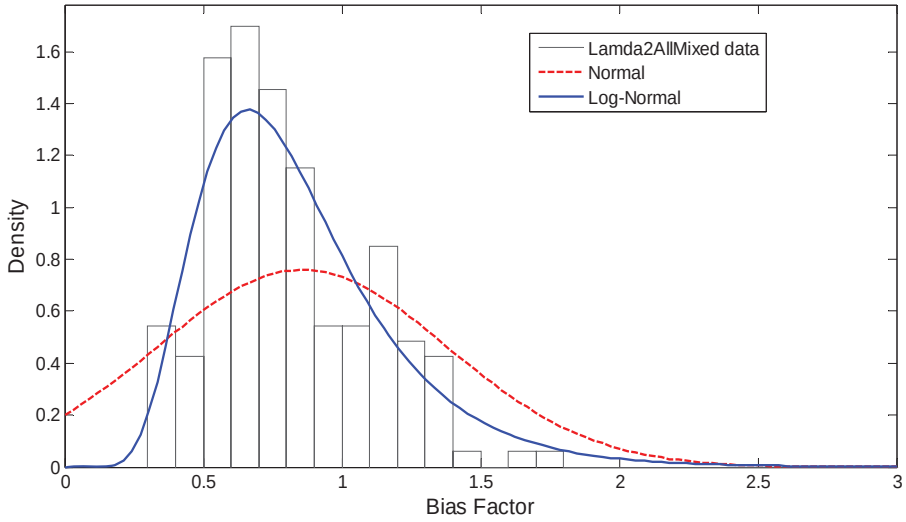


Fig 7.9a Histogram and frequency distribution of bias factor λ2 for 165cases of concrete piles in Mixed soils using the α-Tomlinson and Nordlund/Thurman method (Su: Hara, ϕ: P) in Vietnam

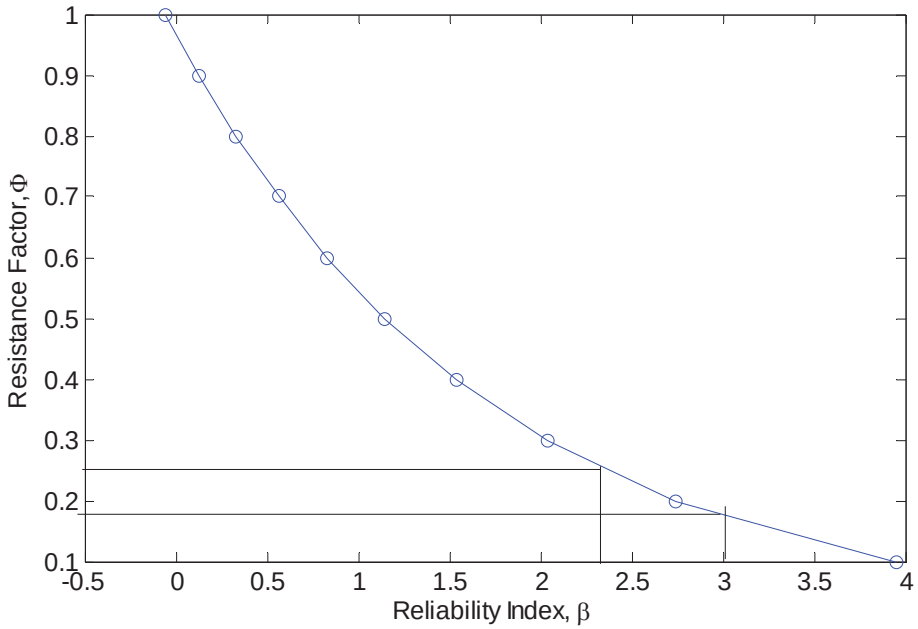


Fig 7.9bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the α-Tomlinson and Nordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Vietnam

Table 7.3a Summary of calibration resistance factor for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Nordlund-Thurman, Shmertmann SPT method in North, Center and South of Vietnam

		Data from North, South and Central of Vietnam														
		Φ from Peck, Hanson and Thornburn							Φ from Schmertmann							
		α-Tomlinson &Nordlund-Thurman		α-API &Nordlund-Thurman		λ &Nordlund-Thurman		β Burland &NordlundThurman	α-Tomlinson &Nordlund-Thurman		α-API &Nordlund-Thurman		λ &Nordlund-Thurman		β Burland &NordlundThurman	Sch-SPT
		Su-T, P	Su-H	Su-T, P	Su-H	Su-T, P	Su-H		Su-T, P	Su-H	Su-T, P	Su-H	Su-T, P	Su-H		
All 165 cases	No	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8	λ9	λ10	λ11	λ12	λ13	λ14	λ15
	avera	0.91	0.86	1.02	0.80	1.02	0.78	0.95	0.74	0.63	0.81	0.65	0.81	0.68	0.76	1.04
	stand	0.28	0.53	0.35	0.27	0.34	0.23	0.35	0.30	0.24	0.37	0.25	0.37	0.26	0.35	0.32
	cov	0.31	0.61	0.34	0.33	0.33	0.30	0.37	0.41	0.38	0.45	0.39	0.45	0.39	0.46	0.30
β =2.33	FOSM	0.50	0.25	0.53	0.42	0.54	0.43	0.46	0.33	0.30	0.33	0.30	0.33	0.32	0.30	0.58
	FORM	0.55	0.26	0.57	0.46	0.58	0.48	0.49	0.35	0.32	0.35	0.33	0.34	0.35	0.32	0.64
	Monte	**0.56**	**0.25**	**0.57**	**0.46**	**0.59**	**0.47**	**0.50**	**0.35**	**0.32**	**0.35**	**0.33**	**0.35**	**0.35**	**0.32**	**0.64**
φ/λ		0.61	0.29	0.56	0.57	0.57	0.61	0.52	0.48	0.51	0.43	0.50	0.43	0.51	0.42	0.61
FS		2.5	5.5	2.4	3.0	2.3	2.9	2.8	3.9	4.3	3.9	4.2	4.0	4.0	4.3	2.2
FS x λ		*2.2*	*4.7*	*2.4*	*2.4*	*2.4*	*2.2*	*2.6*	*2.9*	*2.7*	*3.2*	*2.7*	*3.2*	*2.7*	*3.3*	*2.3*
β =3.00	FOSM	0.39	0.16	0.40	0.33	0.42	0.34	0.35	0.24	0.22	0.24	0.23	0.24	0.24	0.22	0.45
	FORM	0.45	0.17	0.45	0.37	0.47	0.39	0.39	0.27	0.25	0.26	0.25	0.26	0.27	0.24	0.51
	Monte	**0.45**	**0.17**	**0.46**	**0.37**	**0.47**	**0.38**	**0.38**	**0.27**	**0.24**	**0.26**	**0.25**	**0.25**	**0.27**	**0.24**	**0.51**
φ/λ		0.50	0.20	0.45	0.46	0.46	0.50	0.40	0.36	0.39	0.32	0.39	0.31	0.39	0.31	0.49
FS		3.0	8.2	3.0	3.7	2.9	3.6	3.6	5.2	5.6	5.3	5.5	5.4	5.1	5.8	2.7
FS x λ		2.8	7.0	3.1	3.0	3.0	2.8	3.4	3.8	3.5	4.3	3.6	4.4	3.5	4.4	2.8
Good result		good		good		good		good								good

Table 7.3b Summary of calibration resistance factor for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Nordlund-Thurman, ShmertmannSPT method in North of Vietnam

		Data from North of Vietnam														
		Φ from Peck, Hanson and Thornburn							Φ from Schmertmann							
		α-Tomlinson &Nordlund-Thurman		α-API &Nordlund-Thurman		λ &Nordlund-Thurman		β Burland &NordlundThurman	α-Tomlinson &Nordlund-Thurman		α-API &Nordlund-Thurman		λ &Nordlund-Thurman		β Burland Nordlund Thurman	SPT Sch
		Su-T, P	Su- H	Su-T, P	Su-H	Su-T, P	Su-H		Su-T, P	Su-H	Su-T, P	Su-H	Su-T, P	Su-H		
North 99 cases	No	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8	λ9	λ10	λ11	λ12	λ13	λ14	λ15
	avera	0.86	0.75	0.97	0.80	0.99	0.77	0.91	0.66	0.57	0.71	0.58	0.74	0.59	0.67	1.07
	stand	0.25	0.24	0.31	0.25	0.31	0.23	0.31	0.24	0.21	0.29	0.19	0.31	0.20	0.27	0.31
	cov	0.29	0.32	0.32	0.32	0.32	0.29	0.34	0.36	0.37	0.40	0.33	0.42	0.33	0.40	0.29
β =2.33	FOSM	0.491	0.400	0.526	0.437	0.537	0.440	0.474	0.328	0.281	0.325	0.311	0.322	0.311	0.309	0.612
	FORM	0.533	0.433	0.570	0.475	0.583	0.478	0.512	0.355	0.295	0.348	0.335	0.345	0.335	0.328	0.670
	Monte	**0.537**	**0.434**	**0.572**	**0.474**	**0.582**	**0.480**	**0.515**	**0.351**	**0.300**	**0.346**	**0.339**	**0.340**	**0.335**	**0.330**	**0.665**
φ/λ		0.63	0.58	0.59	0.59	0.59	0.62	0.57	0.53	0.52	0.49	0.58	0.46	0.57	0.49	0.62
FS		2.6	3.2	2.4	2.9	2.4	2.9	2.7	3.9	4.6	4.0	4.1	4.0	4.1	4.2	2.1
FS x λ		2.2	2.4	2.3	2.3	2.3	2.2	2.4	2.6	2.6	2.8	2.4	3.0	2.4	2.8	2.2
β =3.00	FOSM	0.386	0.309	0.407	0.339	0.417	0.345	0.364	0.249	0.212	0.241	0.240	0.236	0.240	0.230	0.482
	FORM	0.438	0.350	0.453	0.382	0.465	0.390	0.405	0.275	0.235	0.273	0.270	0.260	0.270	0.255	0.542
	Monte	**0.434**	**0.348**	**0.459**	**0.386**	**0.468**	**0.390**	**0.406**	**0.277**	**0.232**	**0.271**	**0.267**	**0.256**	**0.267**	**0.255**	**0.539**
φ/λ		0.51	0.47	0.47	0.48	0.47	0.51	0.45	0.42	0.41	0.38	0.46	0.35	0.45	0.38	0.51
FS		3.2	4.0	3.0	3.6	2.9	3.5	3.4	5.0	5.9	5.1	5.2	5.4	5.1	5.4	2.5
FS x λ		2.7	3.0	2.9	2.9	2.9	2.7	3.1	3.3	3.4	3.6	3.0	4.0	3.0	3.6	2.7
Good result		good		good		good		good								good

Table 7.3c Summary of calibration resistance factor for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Nordlund-Thurman, Shmertmann SPT method in Central of Vietnam

		Data from Central of Vietnam														
		Φ from Peck, Hanson and Thornburn							Φ from Schmertmann							
		α-Tomlinson Nordlund-Thurman		α-API Nordlund& Thurman		λ Nordlund-Thurman		β Burland Nordlund Thurman	α-Tomlinson Nordlund Thurman		α-APINordlund Thurman		λ Nordlund Thurman		β Burland/ Nordlund Thurman	SPT Sch
		Su-T, P	Su- H	Su-T, P	Su-H	Su-T, P	Su-H		Su-T, P	Su-H	Su-T, P	Su-H	Su-T, P	Su-H		
Central 41 cases	No	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8	λ9	λ10	λ11	λ12	λ13	λ14	λ15
	mean	0.98	0.71	1.14	0.77	1.12	0.76	1.00	0.95	0.74	1.06	0.83	1.02	0.95	0.98	0.87
	stand	0.24	0.18	0.29	0.23	0.31	0.24	0.29	0.29	0.23	0.36	0.26	0.39	0.22	0.35	0.28
	cov	0.24	0.26	0.25	0.30	0.28	0.31	0.29	0.31	0.31	0.34	0.31	0.38	0.23	0.36	0.33
β =2.33	FOSM	0.618	0.434	0.703	0.433	0.661	0.416	0.573	0.524	0.414	0.547	0.454	0.483	0.615	0.488	0.483
	FORM	0.685	0.480	0.780	0.470	0.720	0.451	0.628	0.562	0.450	0.588	0.490	0.510	0.682	0.525	0.495
	Monte	**0.688**	**0.480**	**0.776**	**0.467**	**0.717**	**0.446**	**0.624**	**0.563**	**0.451**	**0.581**	**0.491**	**0.503**	**0.697**	**0.520**	**0.494**
φ/λ		0.70	0.68	0.68	0.60	0.64	0.59	0.62	0.59	0.61	0.55	0.59	0.49	0.73	0.53	0.57
FS		2.0	2.9	1.8	2.9	1.9	3.1	2.2	2.4	3.0	2.4	2.8	2.7	2.0	2.6	2.8
FS x λ		2.0	2.0	2.0	2.3	2.1	2.3	2.2	2.3	2.3	2.5	2.3	2.8	1.9	2.6	2.4
β =3.00	FOSM	0.497	0.347	0.563	0.338	0.524	0.323	0.451	0.408	0.323	0.419	0.353	0.362	0.498	0.370	0.359
	FORM	0.575	0.398	0.645	0.380	0.590	0.360	0.508	0.453	0.370	0.460	0.390	0.392	0.582	0.408	0.397
	Monte	**0.578**	**0.402**	**0.645**	**0.377**	**0.589**	**0.360**	**0.504**	**0.450**	**0.367**	**0.451**	**0.392**	**0.387**	**0.591**	**0.405**	**0.398**
φ/λ		0.59	0.57	0.56	0.49	0.53	0.48	0.50	0.47	0.49	0.42	0.47	0.38	0.62	0.41	0.46
FS		2.4	3.4	2.1	3.6	2.3	3.8	2.7	3.1	3.7	3.1	3.5	3.5	2.3	3.4	3.5
FS x λ		2.3	2.4	2.4	2.8	2.6	2.9	2.7	2.9	2.8	3.2	2.9	3.6	2.2	3.3	3.0
Good result		good		good				good						good		good

Table 7.3d Summary of calibration resistance factor for driven pile usingα-Tomlinson, α-API method, λ method, β-Burland, Nordlund-Thurman, ShmertmannSPT method in South of Vietnam

		Data from South of Vietnam														
		Φ from Peck, Hanson and Thornburn							Φ from Schmertmann							
		α-Tomlinson Nordlund-Thurman		α-API Nordlund-Thurman		λ Nordlund-Thurman		β Burland Nordlund Thurman	α-Tomlinson Nordlund Thurman		α-API Nordlund Thurman		λ Nordlund Thurman		β Burland Nordlund Thurman	SPT Sch
		Su-T,P	Su-H	Su-T,P	Su-H	Su-T,P	Su-H		Su-T,P	Su-H	Su-T,P	Su-H	Su-T,P	Su-H		
South 25 cases	No	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8	λ9	λ10	λ11	λ12	λ13	λ14	λ15
	mean	0.97	1.53	1.03	0.87	1.00	0.83	1.03	0.72	0.65	0.76	0.65	0.74	0.62	0.76	1.25
	stand	0.39	1.01	0.51	0.36	0.45	0.27	0.56	0.40	0.31	0.46	0.33	0.42	0.27	0.49	0.27
	cov	0.40	0.66	0.50	0.41	0.45	0.32	0.54	0.55	0.47	0.60	0.51	0.57	0.44	0.64	0.21
β =2.33	FOSM	0.439	0.397	0.377	0.388	0.409	0.444	0.344	0.240	0.266	0.222	0.231	0.236	0.257	0.206	0.818
	FORM	0.472	0.405	0.390	0.410	0.425	0.475	0.353	0.253	0.260	0.225	0.245	0.245	0.270	0.210	0.925
	Monte	**0.492**	**0.403**	**0.391**	**0.410**	**0.427**	**0.478**	**0.357**	**0.259**	**0.261**	**0.227**	**0.250**	**0.242**	**0.268**	**0.210**	**0.936**
φ/λ		0.51	0.26	0.38	0.47	0.43	0.58	0.35	0.36	0.40	0.30	0.39	0.33	0.43	0.28	0.75
FS		2.8	3.4	3.5	3.4	3.2	2.9	3.9	5.3	5.3	6.0	5.5	5.7	5.1	6.6	1.5
FS x λ		2.7	5.2	3.6	2.9	3.2	2.4	4.0	3.8	3.4	4.6	3.6	4.2	3.2	5.0	1.8
β =3	FOSM	0.326	0.259	0.266	0.287	0.296	0.344	0.238	0.165	0.179	0.149	0.162	0.161	0.187	0.135	0.676
	FORM	0.362	0.268	0.280	0.312	0.320	0.380	0.253	0.181	1.190	0.155	0.175	0.175	0.200	0.140	0.790
	Monte	**0.381**	**0.266**	**0.281**	**0.308**	**0.318**	**0.383**	**0.250**	**0.183**	**0.189**	**0.155**	**0.180**	**0.167**	**0.201**	**0.138**	**0.801**
φ/λ		**0.39**	**0.17**	**0.27**	**0.35**	**0.32**	**0.46**	**0.24**	**0.25**	**0.29**	**0.20**	**0.28**	**0.22**	**0.33**	**0.18**	**0.64**
FS		**3.6**	**5.2**	**4.9**	**4.5**	**4.3**	**3.6**	**5.5**	**7.5**	**7.3**	**8.9**	**7.6**	**8.3**	**6.8**	**9.9**	**1.7**
FS x λ		**3.5**	**7.9**	**5.0**	**3.9**	**4.3**	**3.0**	**5.7**	**5.4**	**4.7**	**6.7**	**4.9**	**6.1**	**4.2**	**7.6**	**2.1**
Good result		good		good		good		good								good

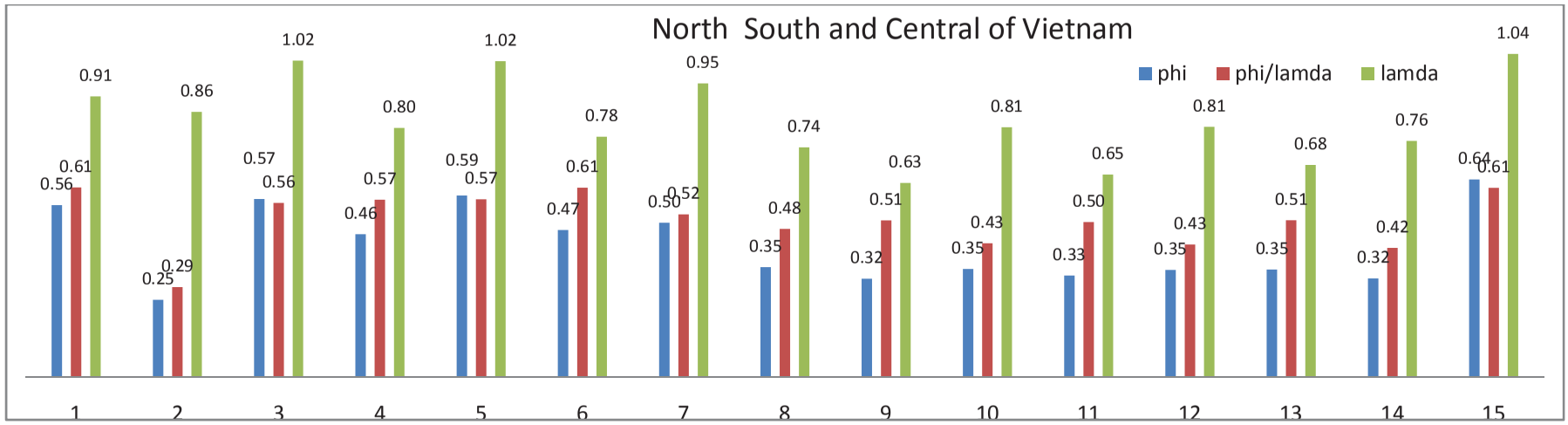


Figure 7.10a Resistance factor, efficiency factor, equivalent factor of safety to ASD for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Nordlund-Thurman, Shmertmann SPT method in Vietnam with β =2.33

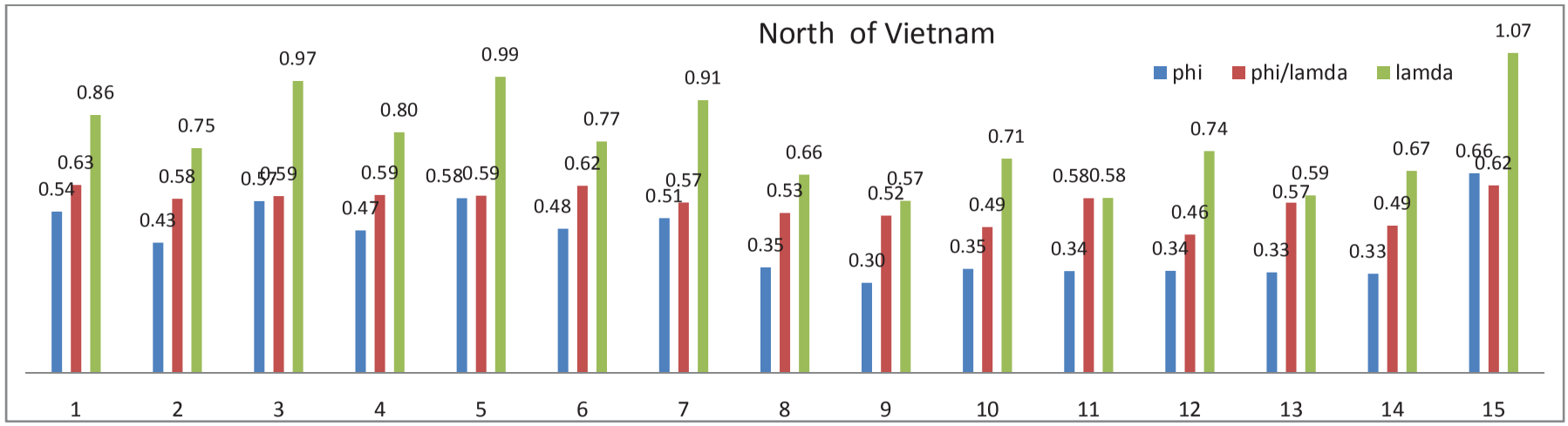


Figure7.10b Resistance factor, efficiency factor, equivalent factor of safety to ASD for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Nordlund-Thurman, Shmertmann SPT method in North of Vietnam with β =2.33

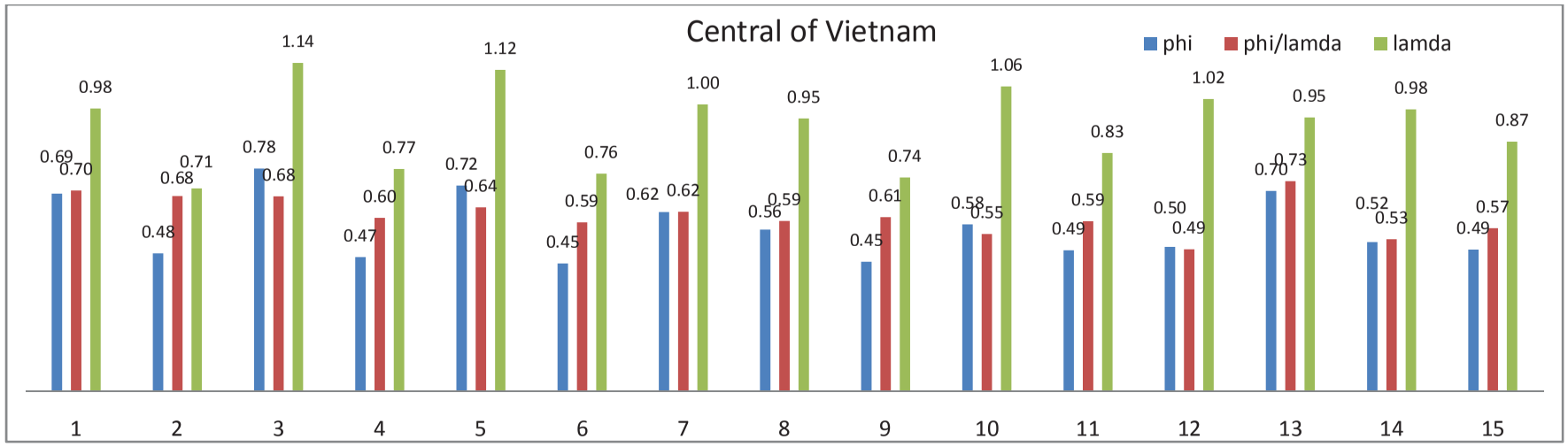


Figure7.11c Resistance factor, efficiency factor, equivalent factor of safety to ASD for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Nordlund-Thurman, Shmertmann SPT method in Central of Vietnam with β =2.33

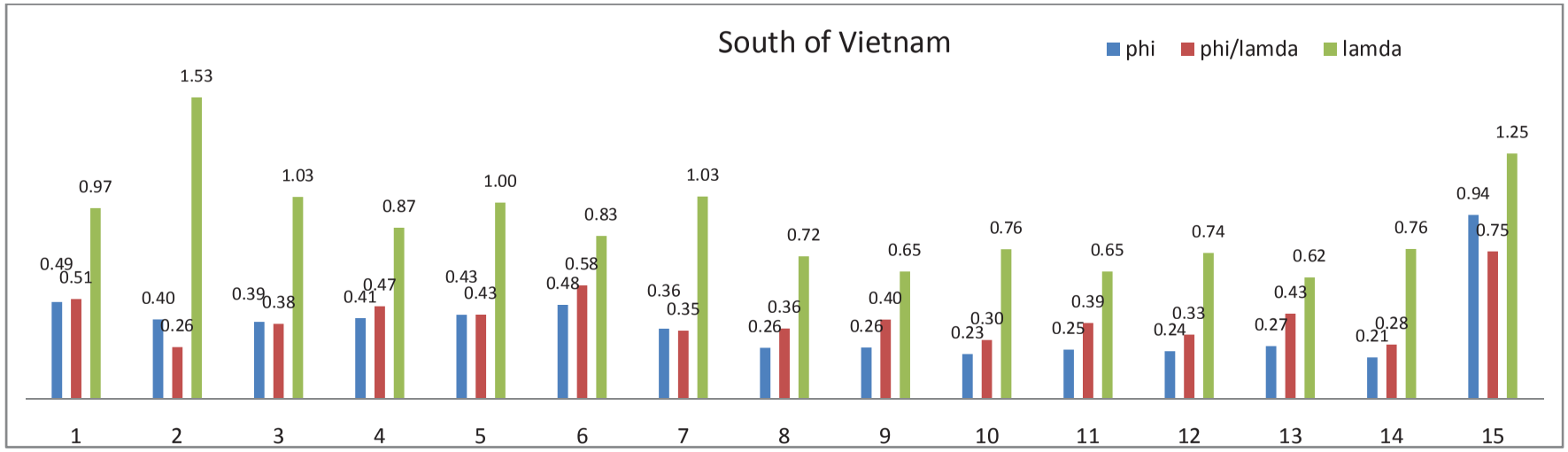


Figure7.11d Resistance factor, efficiency factor, equivalent factor of safety to ASD for driven pile using α-Tomlinson, α-API method, λ method, β-Burland, Nordlund-Thurman, Shmertmann SPT method in South of Vietnam with β =2.33

7.5.4 Statistical sample size requirements for calibration the resistance factor for driven piles in Vietnam

To calibrate the resistance factor for driven piles requires collecting a certain number of the static load tests and soil profiles data. To find out how many data are needed for calibration the resistance factor, a number of bias factor data sets from 5 data to 100 data with increment of one data was randomly picked up 100 times from 165 data for driven piles in mixed soil and each time pick up the resistance factors was calibrated by using Monte-Carlo simulation method and mean value for each set of data was calculated. Figure 7.12, 7.13, 7.14, 7.15 and 7.16 show the number of data sets versus the resistance factor for driven piles in mixed soil using different methods. From the result, number of data is need for calibration for resistance factor is 40 data for driven piles since the number of data more than 40 data the resistance factor calculated is almost the same.

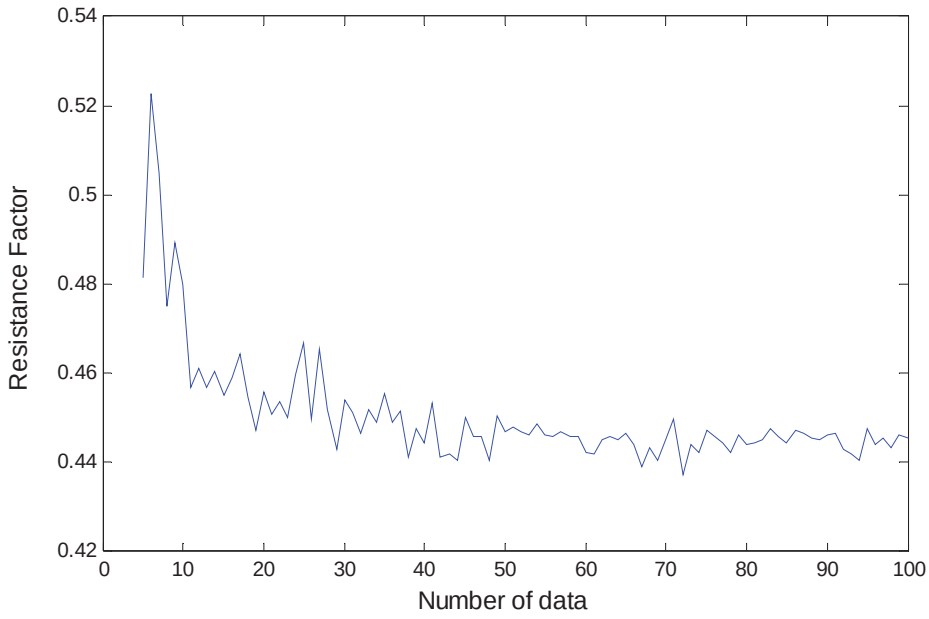


Fig 7.12 Number of data versus the resistance factor Φ with β_T =3.0 for driven piles in mixed soil from North, Central and South of Vietnam using α-Tomlinson & Nordlund-Thurman method (Su from Terzaghi and Peck and Φ from Peck, Hanson and Thornburn)

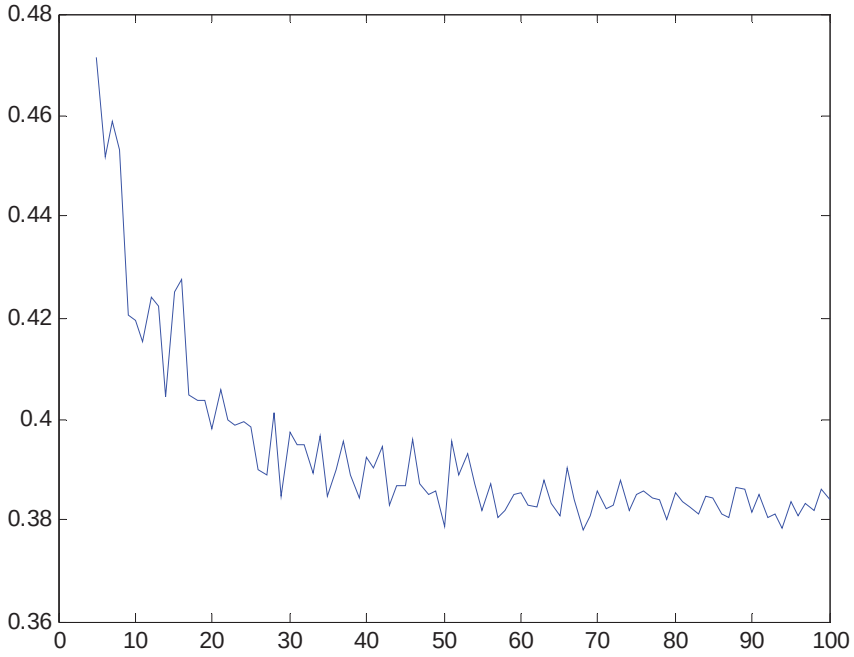


Fig 7.13 Number of data versus the resistance factor Φwith β_T =3.0 for driven piles in mixed soil from North, Central and South of Vietnam using β Burland & Northlund-Thurman method (Φ from Peck, Hanson and Thornburn)

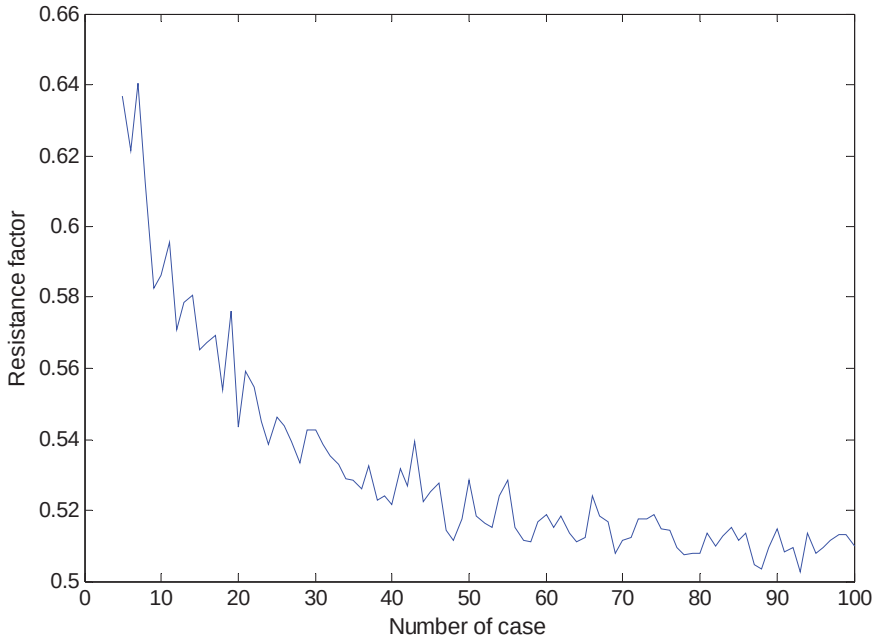


Fig 7.14 Number of data versus the resistance factor Φ with β_T =3.0 for driven piles in mixed soil from North, Central and South of Vietnam using Shmertmann SPT method

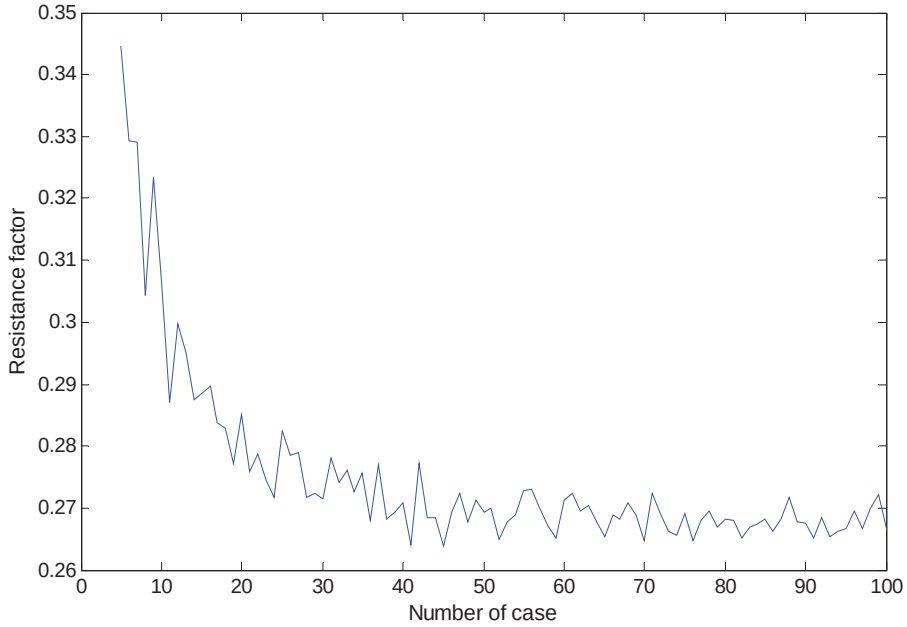


Fig 7.15 Number of data versus the resistance factor Φ with β_T =3.0 for driven piles in mixed soil from North, Central and South of Vietnam using α-Tomlinson & Nordlund-Thurman (Su from Terzaghi and Peck)

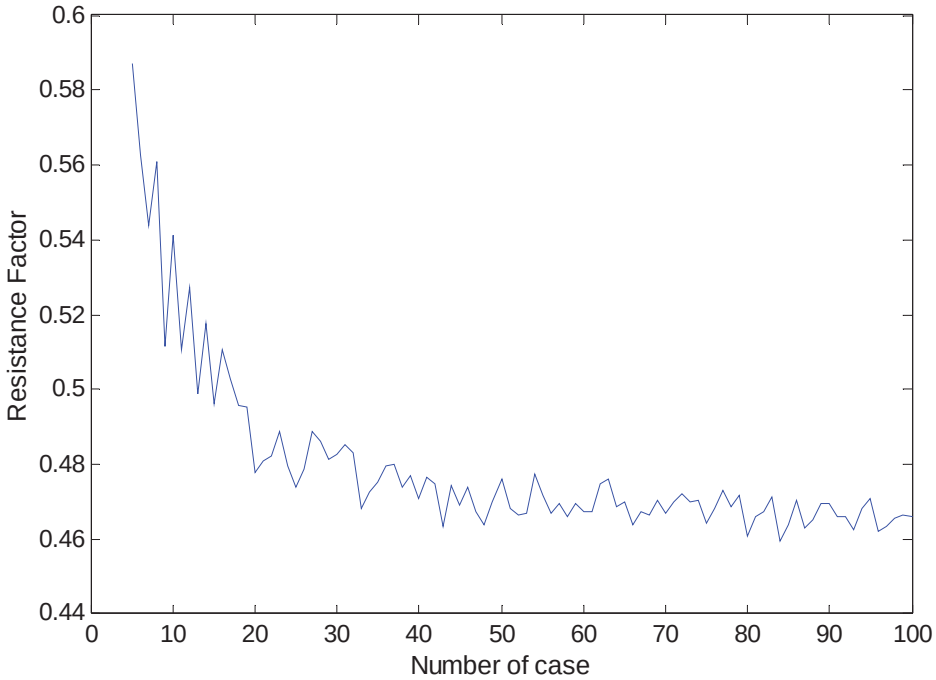


Fig 7.16 Number of data versus the resistance factor Φ with β_T =3.0 for driven piles in mixed soil from North, Central and South of Vietnam using λ & Nordlund-Thurman (Su from Terzaghi and Peck)

7.5.5 Recommendations resistance factor for driven pile in Vietnam

The following correlation between SPT and undrain shear strength Su and friction angle are recommended for calculate the nominal capacity of driven pile in Vietnam

- For piles in Cohesionless soil: using the correlation between friction ϕ and SPT by Peck, Hanson & Thornburn
- For piles in Cohesive soil: using the correlation between Su and SPT by Hara
- For piles in Mixed soil: using the correlation between Su and SPT by Terzaghi and Peck and the correlation between friction ϕ and SPT by Peck, Hanson & Thornburn

Table 7.4 shows the recommendation resistance factors for driven piles design in Vietnam including North, Central and South of Vietnam and comparing with the AASHTO current design specifications to determine the percent increase (+%) or decrease (-%) in the factored capacity. For example, the developed resistance factor of the SPT-Meyerhof method in sand soil was about 56% greater than the factor provided in 2012 AASHTO specifications. For clay soils, the developed resistance factor for β-method using all data from Vietnam was found to be around 130% or 230%using data from South of Vietnam greater than those recommended by AASHTO. For mixed soils, a significant increase of about, 64%, 80% or 54% in the resistance factors was observed for β-Nordlund & Thurman method in North, Central or all data in Vietnam compared to AASHTO. Moreover, an increase in the resistance factors of about 51%, 37%, 9% and 29% was obtained for the α -Tomlinson, Nordlund &Thurman in North, Central, South and All in Vietnam.

Table 7.4 Recommendation of Resistance Factor for Driven Pile in Vietnam with $\beta_T = 3.0$

Soil Type	Static Method	AASHTO 2012	Φ Total	Φ North	Φ Central	Φ South
Sand	Nordlund&Thurman	0.45	0.40 (-11%)	0.39(-13%)	-	-
	Schmertmann SPT	-	0.60	0.58	-	-
	Meyerhof SPT	0.3	0.47 (+56%)	0.47 (+56%)	-	-
Clay	α -Tomlinson	0.35	0.32 (+8%)	0.44 (+26%)	0.88 (+152%)	-
	α- API	-	0.38	0.36	0.85	-
	λ	0.4	0.63 (+58%)	0.35 (-38%)	0.78 (+95%)	-
	β	0.25	0.57 (+128%)	0.52 (+1.08%)	0.82 (+228%)	-
	Schmertmann SPT		0.49	0.47	0.91	-
Mixed	α -Tomlinson, Nordlund&Thurman	0.35	0.45 (+29%)	0.43 (+51%)	0.58 (+37%)	0.38 (+9%)
	α - API, Nordlund& Thurman		0.46	0.46	0.65	0.28
	λ, Nordlund&Thurman	0.4	0.47 (+18%)	0.47 (+18%)	0.59 (+48%)	0.32 (-20%)
	β Nordlund&Thurman	0.25	0.38 (+52%)	0.41 (+64%)	0.45 (+80%)	0.25 (0%)
	Schmertmann SPT		0.51	0.54	0.4	0.80

8. Calibration Resistance Factor for Drilled Shafts Vietnam

In this chapter, resistance factors for drilled Shaft in Vietnam are developed for FHWA method and Reese & Wight method. Also the same with driven pile, calibration of the resistance factors for each analysis method is presented separately and discussed in detail, including histograms and frequency distribution for each case attained using database was collected in Vietnam by author. For the resistance factors corresponding to a wide range of target reliability indices, a sensitivity analysis is considered in order to provide the designer the freedom to select and determine the degree of conservatism in the design. Efficiency factors are also provided to appropriately compare the economy of different methods. Equivalent factors of safety were back calculated from the developed LRFD resistance factors to compare the ASD approach and determine the percentage of gain in the pile capacity when using the LRFD approach. All the regionally developed resistance factors are thus compared with the current design specifications.

8.1 Procedure to Calibrate Resistance Factors for Drilled Shaft

- Collect the static load tests and soil profile for Drilled Shaft in North, Central and South of Vietnam.
- Calculate the nominal capacity by using FHWA and Reese & Wright method.
- Interpret the static load tests to find the real capacity of drilled shaft and driven piles by using 1" and 0.5% D settlement criterion.
- Calculate the bias factor $\lambda_{Ri} = R_{mi} / R_{ni}$
- Calculate the mean, λ_R, and the coefficient of variation, COV, of the random series λ_{Ri}.
- Calibrate the resistance factor by using First Order Second Method (FORM) and First Order Reliability Method (FORM) and Monte Carlo simulation

8.2 Collection of Drilled Shaft in Vietnam

The calibration resistance factor process for drilled shaft in Vietnam requires an extensive data base. From 2008 to 2012 the author collected 92 static load test and soil profiles for drilled shaft from North, Central and South of Vietnam. The list of all piles including locations, depth and cross section of piles can be found in table G1 in appendix G. All data for drilled shaft from big city in Vietnam such as Hanoi, Haiphong and Saigon

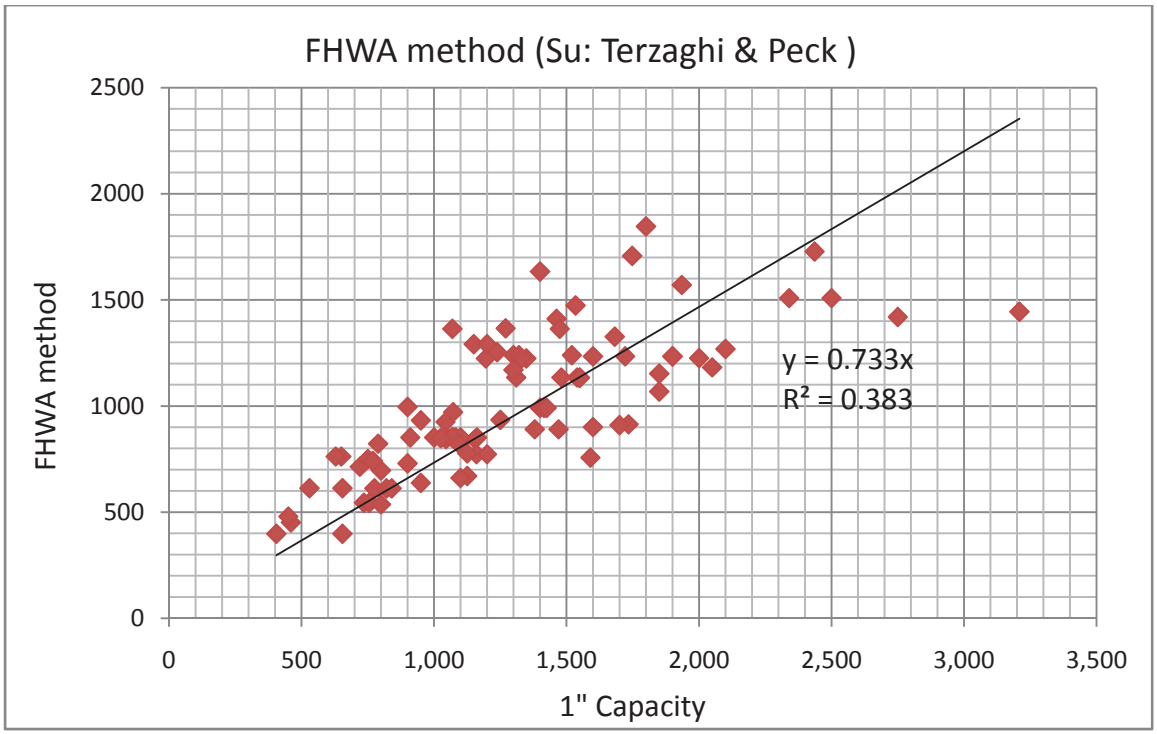
8.3 Measurement Capacity of drilled Shaft

1” and 0.5%D settlement’s criterion were used to interpret the static load test data for driven pile in North, Central and South of Vietnam and the result is shown detail in Table G2 in appendix G.

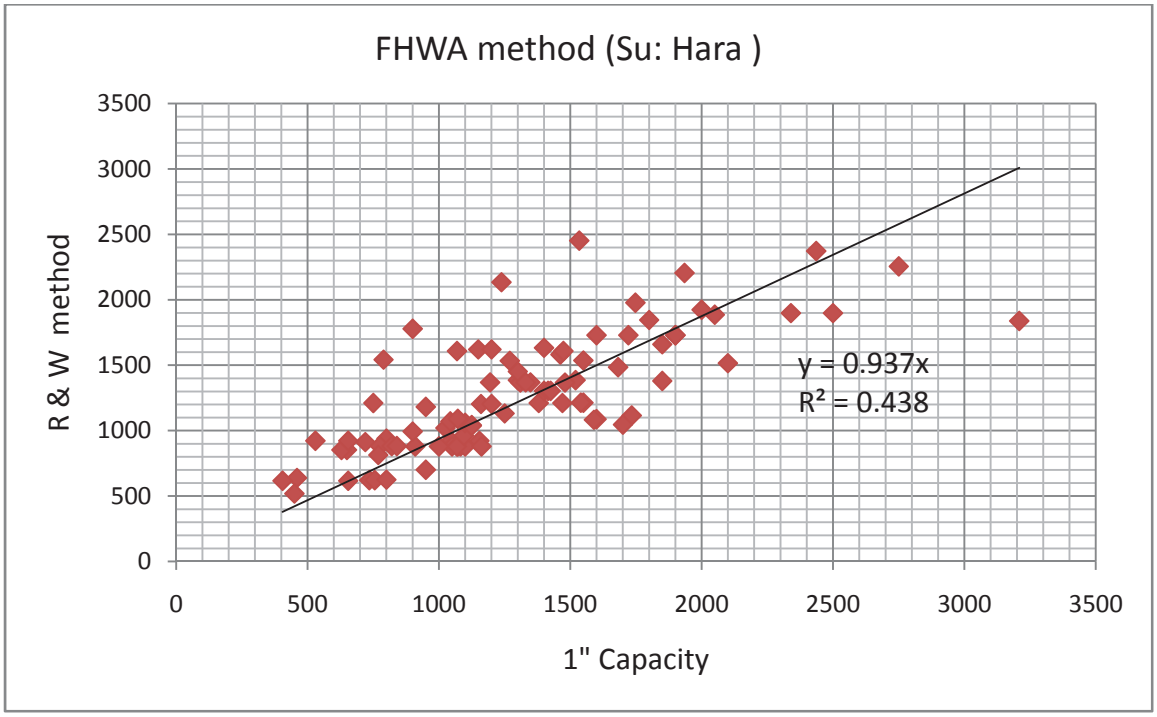
8.4 Nominal Capacity of Drilled Shaft

8.4.1 Nominal Capacity of Concrete Piles in Mixed Soils

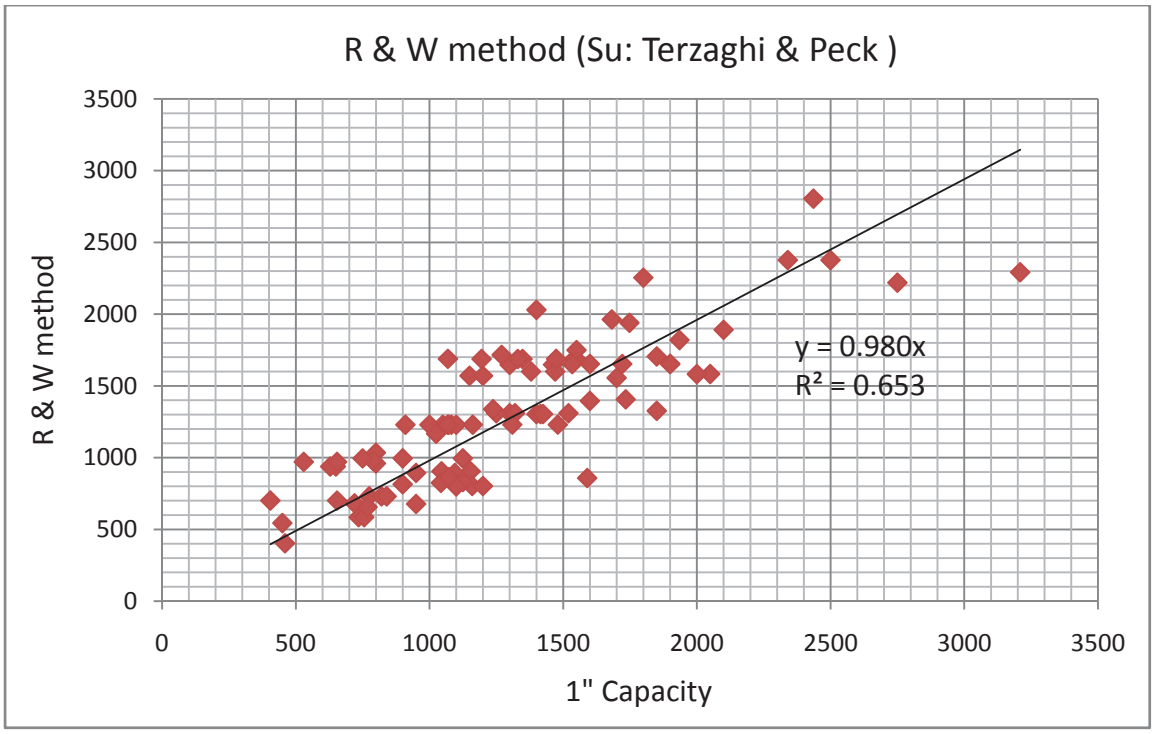
FHWA method and Reese and Wight methods were used for predicting the design nominal capacity of drilled shaft in this researchby using the correlation, previously mentioned in Chapter 3, between Nspt and the un-drain shear strength Su of clay by Terzaghi and Peck (1967) or Hara (1974) The predicted capacity of driven piles in mixed soil is in table G-3 in appendix G.



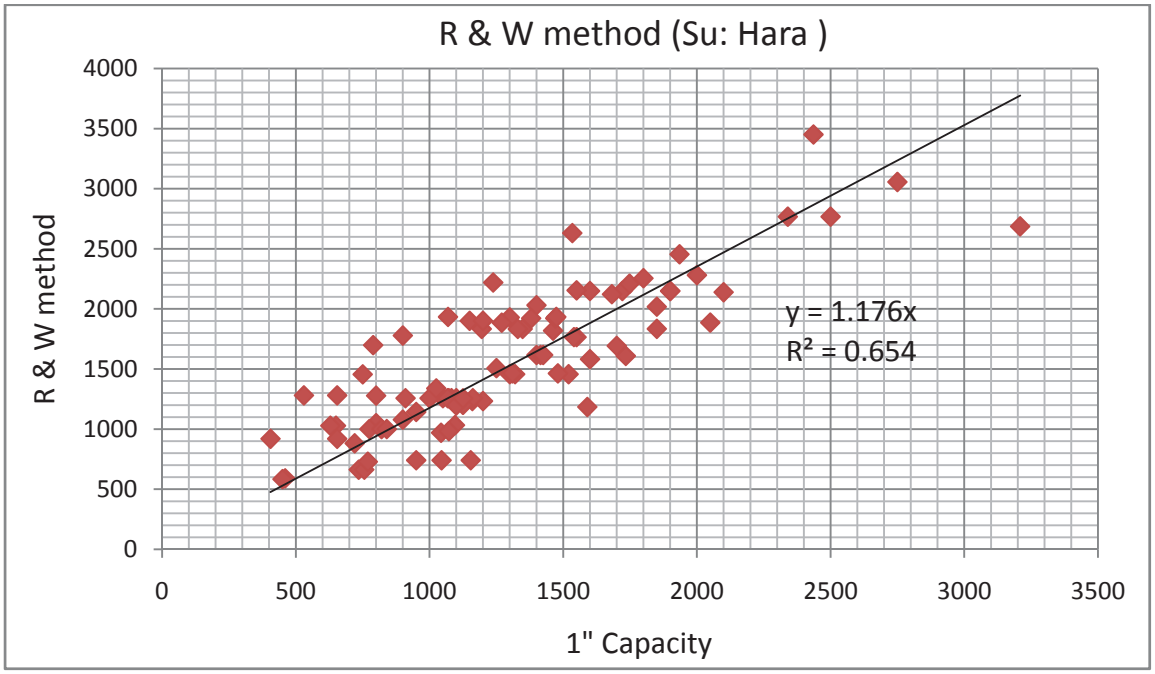
Figures 8.1a: Prediction Capacity using FHWA method (Su: T-P) vs. Measure Capacity of Drilled Shaft using 1" Criterion in Mixed Soils in Vietnam



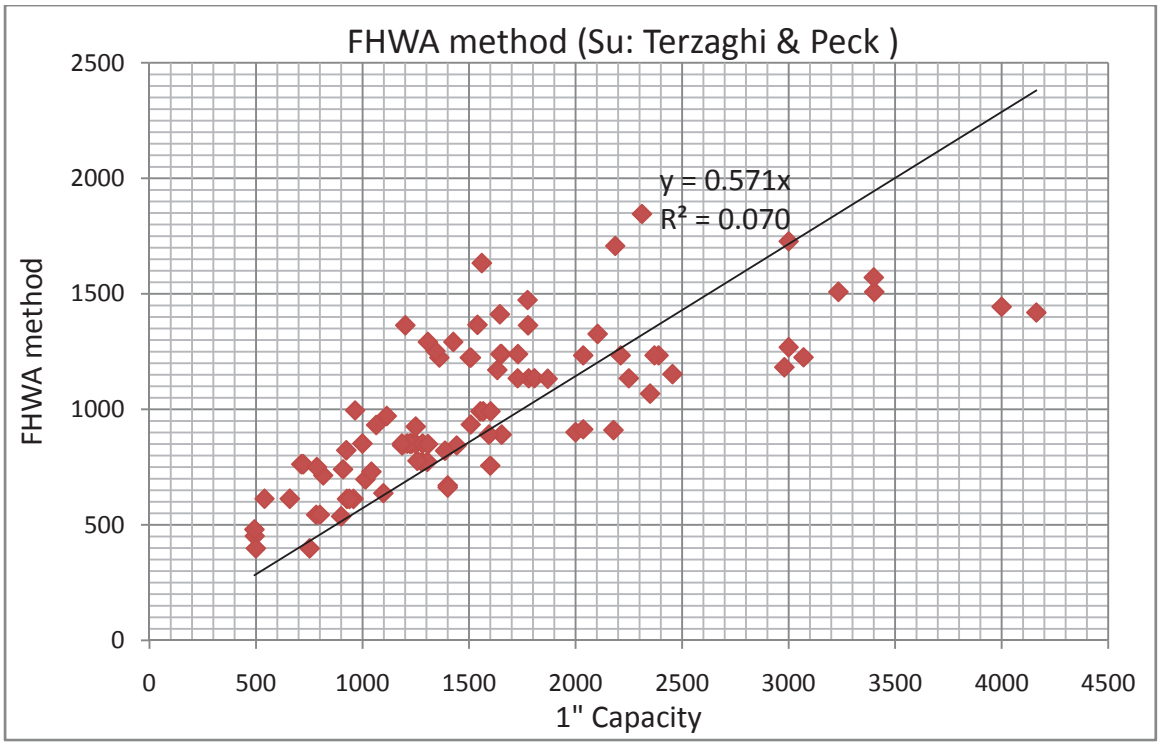
Figures 8.1b: Prediction Capacity using FHWA method (Su: Hara) vs. Measure Capacity of Drilled Shaft using 1" Criterion in Mixed Soils in Vietnam



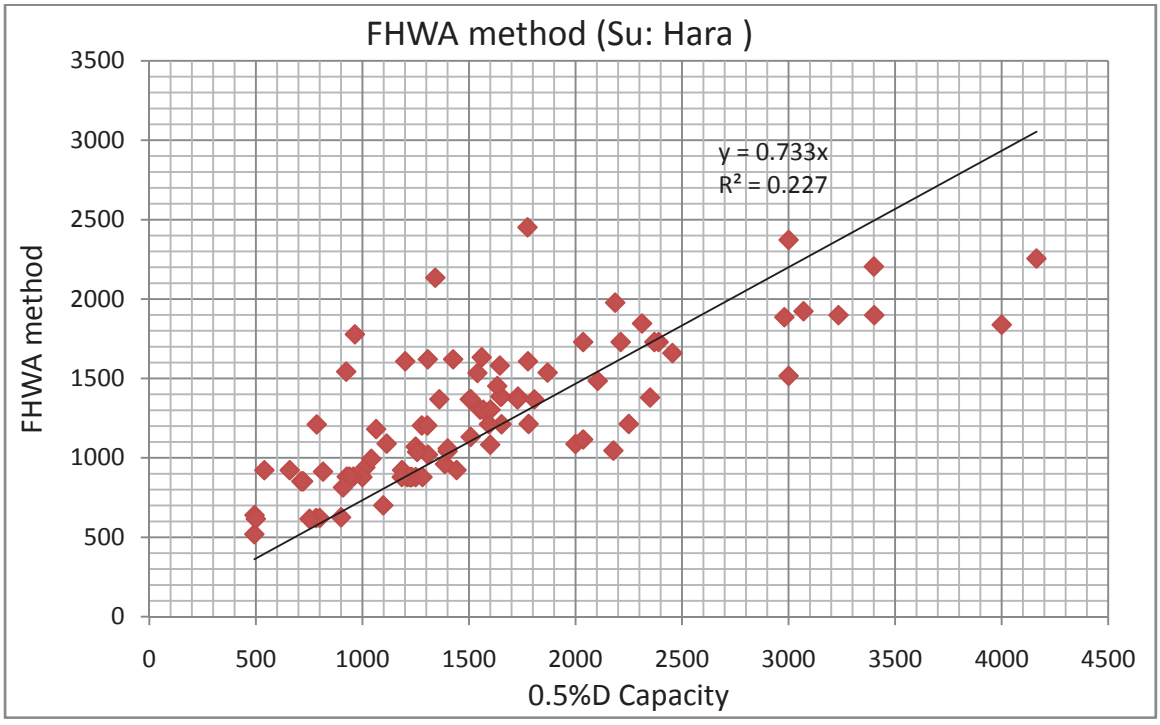
Figures 8.1c: Prediction Capacity using R&W method (Su: T-P) vs. Measure Capacity of Drilled Shaft using 1" Criterion in Mixed Soils in Vietnam



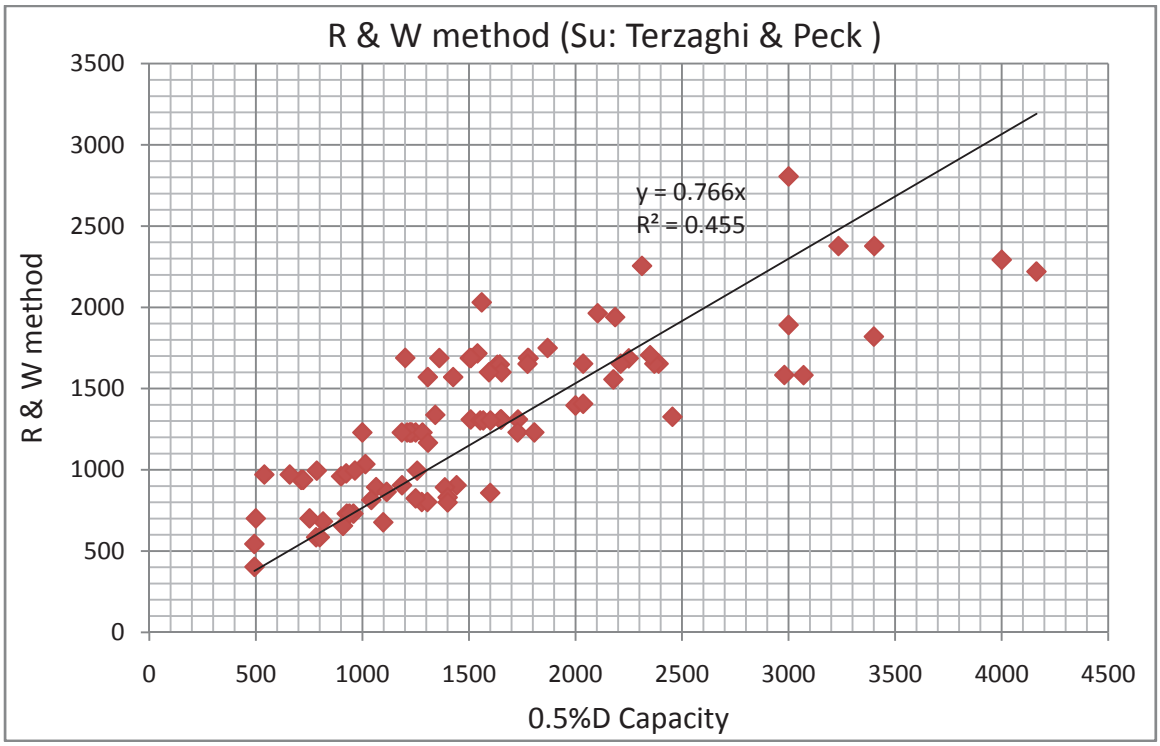
Figures 8.1d: Prediction Capacity using R&W method (Su: Hara) vs. Measure Capacity of Drilled Shaft using 1" Criterion in Mixed Soils in Vietnam



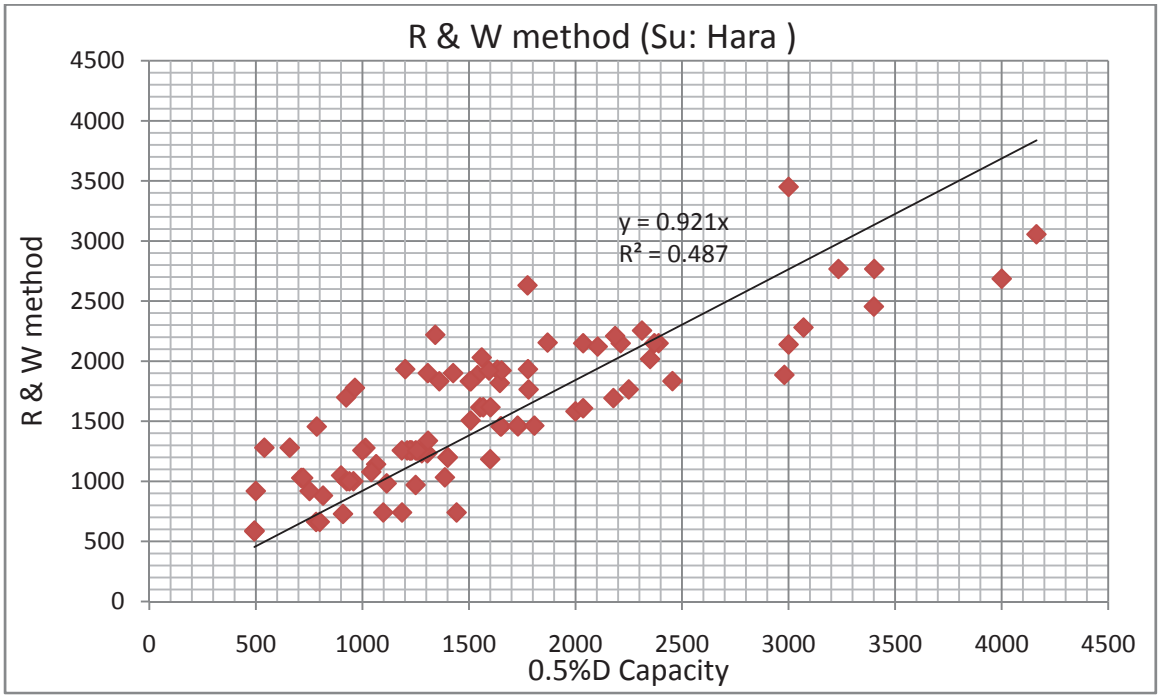
Figures 8.2a: Prediction Capacity using FHWA method (Su: Terzaghi&Peck) vs. Measure Capacity of Drilled Shaft using 1" Criterion in Mixed Soils in Vietnam



Figures 8.2b: Prediction Capacity using FHWA method (Su: Hara) vs. Measure Capacity of Drilled Shaft using 0.5%D Criterion in Mixed Soils in Vietnam



Figures 8.2c: Prediction Capacity using R&W method (Su: T-P) vs. Measure Capacity of Drilled Shaft using 0.5%D Criterion in Mixed Soils in Vietnam



Figures 8.2d: Prediction Capacity using R&W method (Su: Hara) vs. Measure Capacity of Drilled Shaft using 0.5%D Criterion in Mixed Soils in Vietnam

8.5 Calibration of Resistance Factors for Drilled Shaft

The same with driven pile, there are three statistical methods including First Order Second Moment (FOSM), First Order Reliability Methods (FORM) and other advanced methods, such as the Monte Carlo simulation, have been used for performing the reliability analyses to find the resistance factor for drilled shaft by assuming a lognormal distribution of the load and resistance Probability Density Functions (PDFs).Using the E.q 4.47 for FOSM to find the resistance and using Matlab program for FORM and Monte Carlo simulation by following the theory discussed in chapter 4.

8.5.1 Resistant factor for drilled shaft in Mixed Soil

Table 8.1, 8.1a to 8.1f shows the bias factor and the calibration resistance factor as well as efficiency factor (φ/λ), equivalent factor of safety to ASD and actual mean factor of safety for drilled shaft in Mixed soil by FHWA method and Reese& Wright for calculating the nominal capacity in North, Central and South of Vietnam with 1" and 0.5%D settlement criterion. Figure 8.3a and 8.3b is an example of the histogram and frequency distribution of bias factor $\lambda 1$ and an example of resistant factor calibration 92 cases of drilled shaft in mixed soils using the FHWA method with correlation between undrain shear strength Su and SPT by Terzaghi and Peck and using 1" settlement criterion in Vietnam. The other histograms and frequency distributions of bias factor: $\lambda 1$ to$\lambda 8$ and resistant factor calibration: $\Phi 1$ to $\Phi 8$ corresponding to different method for All data, North data, and South data can be found in the figure G-M1-a to G-M8-d in appendix G

Table.8.1 Bias Factor for drilled Shaft in Mixed Soil using FHWA and Reese & Wright method with 1" and 0.5% D settlement criterion.

	1" settlement Criterion				0.5 % D settlementCriterion			
	FHWA method		Reese and Wright method		FHWA method		Reese and Wright method	
	Su (T, P)	Su (Hara)	Su (T,P)	Su (Hara)	Su (T,P)	Su (Hara)	Su (T,P)	Su (Hara)
	$\lambda 1$	$\lambda 2$	$\lambda 3$	$\lambda 4$	$\lambda 5$	$\lambda 6$	$\lambda 7$	$\lambda 8$
NP-M1	1.35	1.18	1.26	1.11	1.44	1.26	1.34	1.18
NP-M2	1.39	1.22	1.29	1.14	1.47	1.29	1.37	1.21

Table 8.1 (cont.)

NP-M3	1.05	0.94	0.99	0.89	1.33	1.19	1.26	1.13
NP-M4	1.07	0.95	1.01	0.91	1.33	1.19	1.26	1.13
NP-M5	1.23	1.10	1.16	1.04	1.40	1.25	1.32	1.19
NP-M6	1.37	1.28	0.92	0.88	1.98	1.85	1.33	1.27
NP-M7	1.36	1.27	0.91	0.87	1.57	1.47	1.06	1.01
NP-M9	1.15	0.96	1.06	0.90	1.52	1.26	1.40	1.18
NP-M10	1.30	1.08	1.20	1.01	1.59	1.32	1.47	1.23
NP-M11	1.37	1.25	1.27	1.56	1.71	1.56	1.59	1.95
NP-M12	1.24	1.13	1.15	1.41	1.41	1.29	1.31	1.60
NP-M13	1.49	1.36	1.40	1.28	1.72	1.57	1.62	1.48
NP-M14	1.02	0.80	1.06	0.83	1.14	0.90	1.19	0.93
NP-M15	1.01	0.79	1.06	0.82	1.14	0.89	1.20	0.93
NP-M16	1.50	0.96	1.45	0.94	1.66	1.06	1.59	1.04
NP-M17	1.55	1.00	1.50	0.97	1.69	1.08	1.63	1.06
NP-M18	1.54	1.10	1.15	0.88	1.94	1.38	1.45	1.11
NP-M19	1.39	1.00	1.04	0.80	1.79	1.28	1.34	1.03
NP-M20	1.54	1.10	1.15	0.88	1.92	1.37	1.43	1.10
NP-M21	1.30	0.93	0.97	0.74	1.65	1.18	1.23	0.95
NP-M22	1.15	0.85	0.77	0.63	1.46	1.08	0.98	0.79
NP-M23	1.27	1.13	0.86	0.79	1.59	1.42	1.07	0.99
NP-M27	1.11	0.90	0.79	0.67	1.40	1.12	0.99	0.85
NP-M28	1.34	1.10	0.95	0.83	1.61	1.33	1.15	1.00
NP-M29	1.02	0.72	1.14	0.78	1.09	0.77	1.23	0.84
NP-M30	1.73	1.09	1.29	1.09	2.52	1.58	1.88	1.58
NP-M31	0.85	0.76	0.69	0.63	0.94	0.84	0.76	0.69
NP-M32	0.83	0.74	0.67	0.61	0.95	0.85	0.77	0.70
NP-M35	1.04	0.92	0.89	0.80	1.17	1.04	1.00	0.90
NP-M36	0.90	0.80	0.77	0.70	1.09	0.97	0.93	0.85
NP-M37	1.24	1.11	1.06	0.96	1.55	1.38	1.33	1.20
NP-M38	0.99	0.89	0.85	0.77	1.11	0.99	0.95	0.86
NP-M39	1.28	1.14	1.09	0.99	1.64	1.46	1.40	1.27
NP-M40	1.65	1.21	0.92	0.76	1.86	1.36	1.03	0.86
NP-M41	1.55	1.14	0.86	0.72	1.79	1.32	1.00	0.83
NP-M42	1.27	1.23	0.88	0.86	1.45	1.40	1.00	0.98
NP-M43	1.26	1.22	0.87	0.85	1.44	1.39	1.00	0.97
NP-M44	1.23	1.19	0.85	0.84	1.42	1.38	0.98	0.96
NP-M45	1.29	1.25	0.89	0.87	1.47	1.42	1.02	0.99
NP-M46	1.25	1.21	0.87	0.85	1.43	1.39	0.99	0.97
NP-M47	1.36	1.32	0.94	0.92	1.51	1.46	1.04	1.02
NP-M48	1.07	1.04	0.74	0.72	1.17	1.14	0.81	0.80

Table 8.1 (cont.)

NP-M49	1.17	1.14	0.81	0.80	1.39	1.35	0.96	0.94
NP-M50	1.21	1.00	0.88	0.77	1.54	1.28	1.12	0.98
NP-M51	1.33	1.14	1.23	1.06	1.69	1.44	1.55	1.34
NP-M52	1.13	0.97	1.26	1.08	1.35	1.17	1.52	1.29
NP-M53	1.23	0.91	1.10	0.83	1.43	1.05	1.28	0.97
NP-M54	0.94	0.87	0.83	0.77	1.03	0.95	0.91	0.84
NP-M55	1.10	0.98	0.80	0.74	1.23	1.10	0.89	0.82
NP-M56	1.09	0.97	0.79	0.73	1.23	1.10	0.89	0.82
NP-M57	0.98	0.87	0.71	0.65	1.11	0.99	0.81	0.74
NP-M58	1.08	0.92	0.87	0.76	1.30	1.11	1.05	0.92
NP-M59	0.78	0.66	0.63	0.55	0.88	0.75	0.71	0.62
NP-M60	1.66	1.39	1.11	0.98	2.36	1.98	1.59	1.40
NP-M61	2.53	2.12	1.70	1.50	3.15	2.64	2.11	1.87
NP-M62	1.92	1.61	1.29	1.14	2.36	1.98	1.59	1.40
NP-M63	1.73	1.34	1.08	0.92	2.20	1.70	1.38	1.16
NP-M64	1.66	1.32	1.05	0.90	2.26	1.79	1.43	1.23
NP-M65	1.55	1.23	0.98	0.85	2.14	1.70	1.36	1.17
NP-M66	1.78	1.47	1.15	1.01	2.22	1.84	1.43	1.26
NP-M67	1.90	1.55	1.23	1.08	2.23	1.83	1.45	1.27
NP-M68	1.61	1.11	1.39	1.01	2.13	1.48	1.85	1.34
NP-M69	1.23	0.88	1.06	0.79	2.16	1.54	1.87	1.39
NP-M70	1.87	1.63	1.09	1.00	2.39	2.08	1.40	1.29
NP-M71	1.49	1.28	0.83	0.76	1.68	1.44	0.94	0.86
NP-M72	1.68	1.08	1.36	0.94	2.09	1.34	1.69	1.16
NP-M73	2.10	1.47	1.85	1.34	2.12	1.48	1.86	1.35
NP-M74	1.66	1.04	1.38	0.92	2.12	1.32	1.75	1.17
NP-M75	1.45	1.08	1.13	0.90	1.62	1.21	1.26	1.00
NP-M76	1.41	1.07	1.07	0.87	1.57	1.19	1.19	0.96
NP-M77	1.43	1.09	1.09	0.88	1.58	1.20	1.20	0.97
NP-M78	1.44	1.09	1.09	0.88	1.62	1.23	1.23	0.99
NP-M79	0.96	0.51	0.81	0.46	1.12	0.60	0.94	0.54
NP-M80	1.00	0.62	0.75	0.52	1.05	0.65	0.79	0.54
NP-M81	1.37	1.01	0.89	0.72	1.65	1.22	1.07	0.87
NP-M82	1.27	0.88	1.06	0.77	1.51	1.05	1.27	0.93
NP-M83	1.34	0.93	1.12	0.82	1.57	1.09	1.31	0.96
NP-M84	1.37	0.95	1.15	0.84	1.53	1.07	1.29	0.94
NP-M85	1.04	0.63	0.93	0.58	1.20	0.72	1.07	0.67
NP-M86	0.84	0.50	0.93	0.47	0.91	0.55	1.00	0.51
CP-M1	1.63	1.04	1.26	0.88	2.51	1.60	1.94	1.35
CP-M2	1.94	1.22	1.24	0.90	2.93	1.85	1.88	1.36

Table 8.1 (cont.)

SP-M3	1.04	0.94	1.17	1.05	1.23	1.12	1.39	1.25
SP-M4	1.10	0.98	1.24	1.09	1.15	1.02	1.29	1.13
SP-M11	0.90	0.51	0.90	0.51	0.97	0.54	0.97	0.54
SP-M12	1.64	1.06	0.93	0.71	1.89	1.22	1.07	0.82
SP-M13	1.02	0.66	0.58	0.44	1.26	0.81	0.71	0.54
SP-M14	1.07	0.71	0.67	0.51	0.88	0.59	0.56	0.42
SP-M15	0.86	0.57	0.55	0.41	1.08	0.71	0.68	0.51
SP-M16	0.89	0.71	0.73	0.61	1.01	0.81	0.83	0.69
SP-M17	0.93	0.74	0.76	0.63	1.10	0.88	0.91	0.75

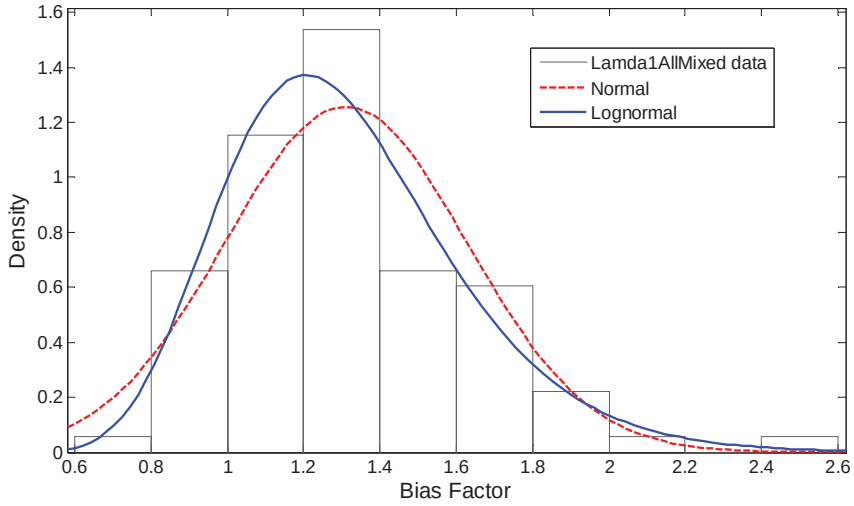


Figure 8.3a. Histogram and frequency distribution of bias factor λ1 for 92 cases of drilled shaft in Mixed soils using the FHWA method (Su: Terzaghi, Peck) and using 1" criterion in Vietnam

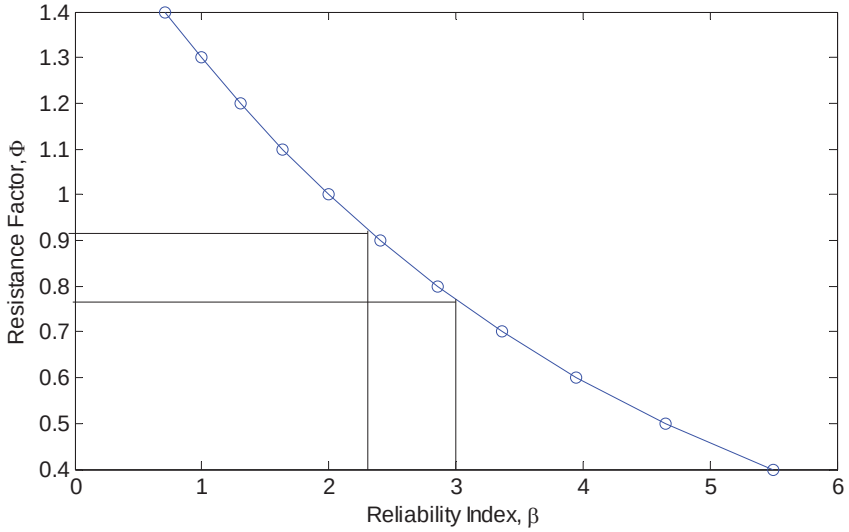


Figure 8.3b. Resistance factor calibration for 92 cases of drilled shaft in Mixed soils using the FHWA method (Su: Terzaghi, Peck) and using 1" criterion in Vietnam

Table 8.1aSummary of calibration resistance factorfor drilled shaft using FHWA and Reese & Wright method with 1" criterion settlement in North, Center and South of Vietnam

		FHWA method		Reese and Wright method	
		Su (Terzaghi, Peck)	Su (Hara)	Su (Terzaghi, Peck)	Su (Hara)
		Φ1	Φ2	Φ3	Φ4
Total	Mean	1.31	1.04	1.02	0.86
92 cases	stand	0.32	0.27	0.24	0.21
	cov	0.24	0.25	0.23	0.25
β =2.33	FOSM	0.826	0.641	0.658	0.530
	FORM	0.920	0.710	0.736	0.585
	MC	**0.924**	**0.714**	**0.742**	**0.591**
φ/λ[1]		0.71	0.68	0.72	0.69
FS[2]		1.49	1.93	1.85	2.33
FS x λ[3]		1.95	2.01	1.90	1.99
β =3	FOSM	0.665	0.513	0.532	0.425
	FORM	0.770	0.592	0.622	0.490
	MC	**0.775**	**0.597**	**0.629**	**0.493**
φ/λ		0.51	0.49	0.52	0.50
FS		2.07	2.68	2.58	3.23
FS x λ		2.71	2.79	2.65	2.77

1 Efficiency factor 2Equivalent factor of safety to ASD 3 Actual mean factor of safety 4 Monte Carlo simulation

Table8.1b Summary of calibration resistance factor for drilled shaft using FHWA and Reese & Wright method with 1" criterion settlement in North of Vietnam

		FHWA method		Reese and Wright method	
		Su (Terzaghi, Peck)	Su (Hara)	Su (Terzaghi, Peck)	Su (Hara)
		Φ1	Φ2	Φ3	Φ4
North	Mean	1.33	1.07	1.04	0.88
92 cases	stand	0.31	0.26	0.23	0.20
	cov	0.23	0.24	0.22	0.23
β =2.33	FOSM	0.853	0.676	0.681	0.562
	FORM	0.950	0.755	0.758	0.625
	MC	**0.966**	**0.778**	**0.765**	**0.641**
φ/λ		0.73	0.73	0.74	0.73
FS		1.42	1.77	1.80	2.15
FS x λ		1.89	1.89	1.87	1.88
β =3	FOSM	0.690	0.545	0.554	0.455
	FORM	0.804	0.625	0.640	0.528
	MC	**0.822**	**0.625**	**0.649**	**0.543**
φ/λ		0.62	0.58	0.62	0.62
FS		1.67	2.20	2.12	2.53
FS x λ		2.22	2.35	2.20	2.22

Table 8.1c Summary of calibration resistance factor for drilled shaft using FHWA and Reese & Wright method with 1" criterion settlement in South of Vietnam

		FHWA method		Reese and Wright method	
		Su (Terzaghi, Peck)	Su (Hara)	Su (Terzaghi, Peck)	Su (Hara)
		Φ1	Φ2	Φ3	Φ4
South	Mean	1.05	0.77	0.84	0.66
10 cases	stand	0.24	0.19	0.25	0.25
	cov	0.23	0.25	0.29	0.38
β =2.33	FOSM	0.682	0.476	0.478	0.317
	FORM	0.760	0.534	0.525	0.350
	Monte	**0.763**	**0.514**	**0.518**	**0.336**
φ/λ		0.73	0.67	0.62	0.51
FS		1.80	2.68	2.65	4.09
FS x λ		1.89	2.05	2.22	2.71
β =3	FOSM	0.553	0.382	0.375	0.238
	FORM	0.640	0.445	0.427	0.265
	Monte	**0.648**	**0.431**	**0.426**	**0.259**
φ/λ		0.62	0.56	0.51	0.39
FS		2.12	3.19	3.23	5.30
FS x λ		2.23	2.44	2.70	3.52

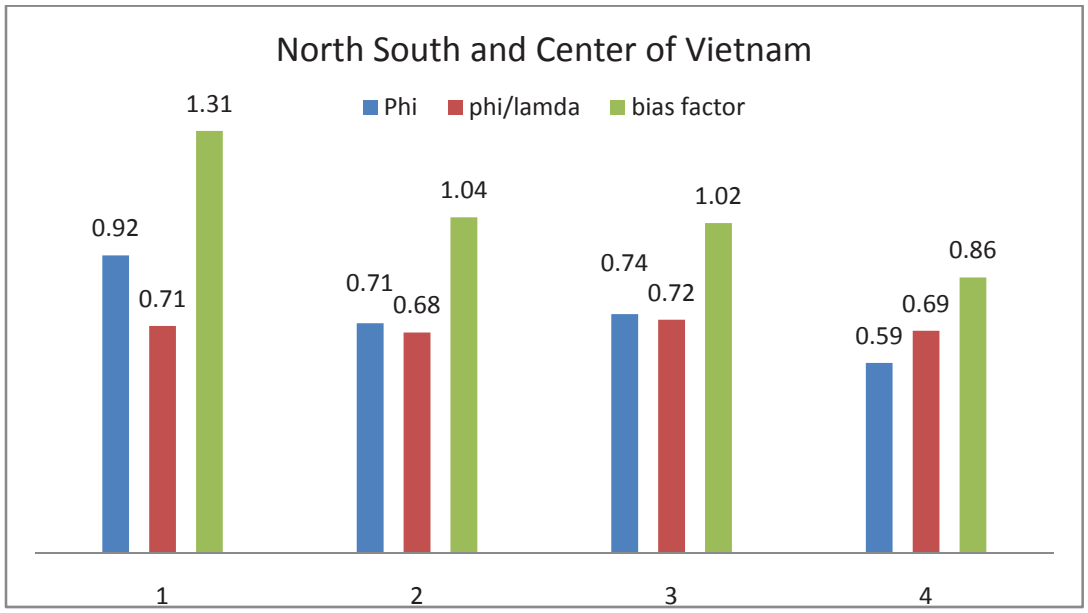


Figure 8.4a. Resistance factor, efficiency factor, equivalent factor of safety to ASD for drilled shaft using FHWA and Reese & Wright method with 1" criterion settlement in North, Center and South of Vietnam

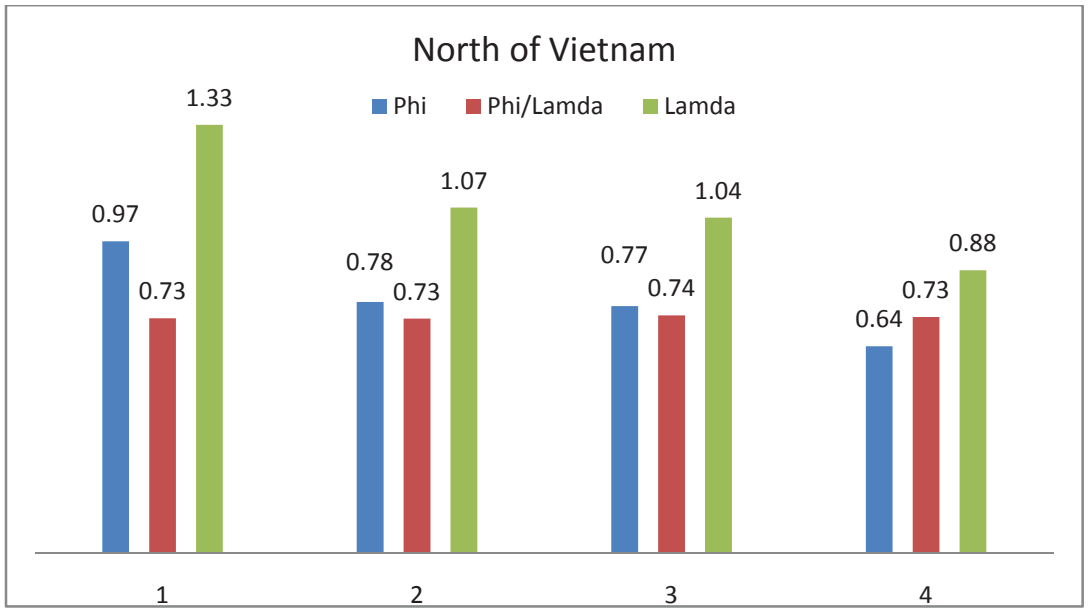


Figure 8.4b. Resistance factor, efficiency factor,equivalent factor of safety to ASD for drilled shaft using FHWA and Reese & Wright method with 1" criterion settlement in North of Vietnam

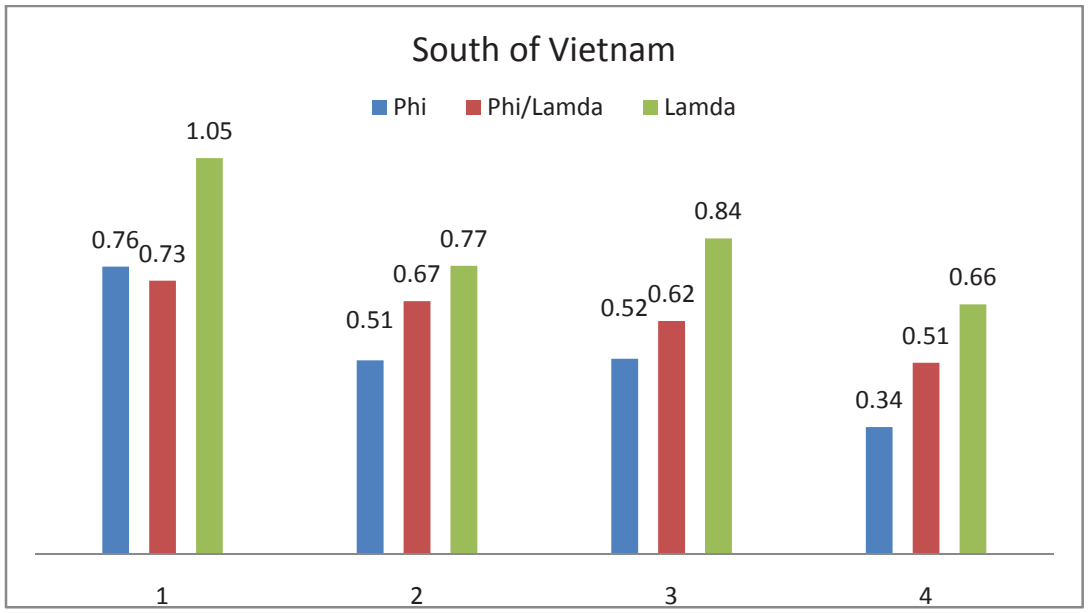


Figure 8.4c. Resistance factor,efficiency factor,equivalent factor of safety to ASD for drilled shaft using FHWA and Reese & Wright method with 1" criterion settlement in South of Vietnam

Table 8.1d Summary of calibration resistance factor for drilled shaft using FHWA and Reese & Wright method with 0.5%D settlement in North, Center and South of Vietnam.

		FHWA method		Reese and Wright method	
		Su (Terzaghi, Peck)	Su (Hara)	Su (Terzaghi, Peck)	Su (Hara)
		λ5	λ6	λ7	λ8
Total	Mean	1.58	1.25	1.23	1.03
92 cases	stand	0.46	0.37	0.32	0.29
	cov	0.29	0.29	0.26	0.28
β =2.33	FOSM	0.900	0.718	0.743	0.604
	FORM	0.975	0.780	0.820	0.660
	Monte	**0.988**	**0.786**	**0.824**	**0.623**
φ/λ		0.63	0.63	0.67	0.61
FS		1.39	1.75	1.67	2.21
FS x λ		2.20	2.19	2.05	2.27
β =3	FOSM	0.707	0.564	0.592	0.478
	FORM	0.795	0.635	0.675	0.542
	Monte	**0.801**	**0.641**	**0.679**	**0.548**
φ/λ		0.51	0.51	0.55	0.53
FS		1.72	2.15	2.02	2.51
FS x λ		2.71	2.69	2.49	2.58

Table 8.1eSummary of calibration resistance factor for drilled shaft using FHWA and Reese & Wright method with 0.5%D settlement in North of Vietnam.

		FHWA method		Reese and Wright method	
		Su (Terzaghi, Peck)	Su (Hara)	Su (Terzaghi, Peck)	Su (Hara)
		λ5	λ6	λ7	λ8
North	Mean	1.60	1.29	1.25	1.05
80 cases	stand	0.43	0.35	0.30	0.27
	cov	0.27	0.27	0.24	0.26
β =2.33	FOSM	0.957	0.768	0.787	0.647
	FORM	1.050	0.850	0.875	0.713
	Monte	**1.072**	**0.850**	**0.873**	**0.730**
φ/λ		0.67	0.66	0.70	0.69
FS		1.28	1.62	1.58	1.88
FS x λ		2.05	2.08	1.96	1.98
β =3	FOSM	0.761	0.610	0.634	0.517
	FORM	0.865	0.693	0.725	0.586
	Monte	**0.887**	**0.697**	**0.731**	**0.615**
φ/λ		0.56	0.54	0.59	0.59
FS		1.55	1.97	1.88	2.24
FS x λ		2.48	2.54	2.34	2.35

Table 8.1f Summary of calibration resistance factor for drilled shaft using FHWA and Reese & Wright method with 0.5%D settlement in South of Vietnam.

		FHWA method		Reese and Wright method	
		Su (Terzaghi, Peck)	Su (Hara)	Su (Terzaghi, Peck)	Su (Hara)
		λ5	λ6	λ7	λ8
South	Mean	1.17	0.86	0.93	0.74
10 cases	stand	0.29	0.23	0.28	0.29
	cov	0.25	0.27	0.30	0.39
β =2.33	FOSM	0.728	0.512	0.528	0.348
	FORM	0.798	0.560	0.580	0.365
	Monte	**0.807**	**0.563**	**0.574**	**0.364**
φ/λ		0.69	0.66	0.61	0.49
FS		1.70	2.44	2.39	3.78
FS x λ		2.00	2.09	2.24	2.79
β =3	FOSM	0.584	0.407	0.414	0.261
	FORM	0.678	0.460	0.460	0.280
	Monte	**0.671**	**0.464**	**0.465**	**0.282**
φ/λ		0.57	0.54	0.50	0.38
FS		2.05	2.96	2.96	4.88
FS x λ		2.41	2.53	2.76	3.61

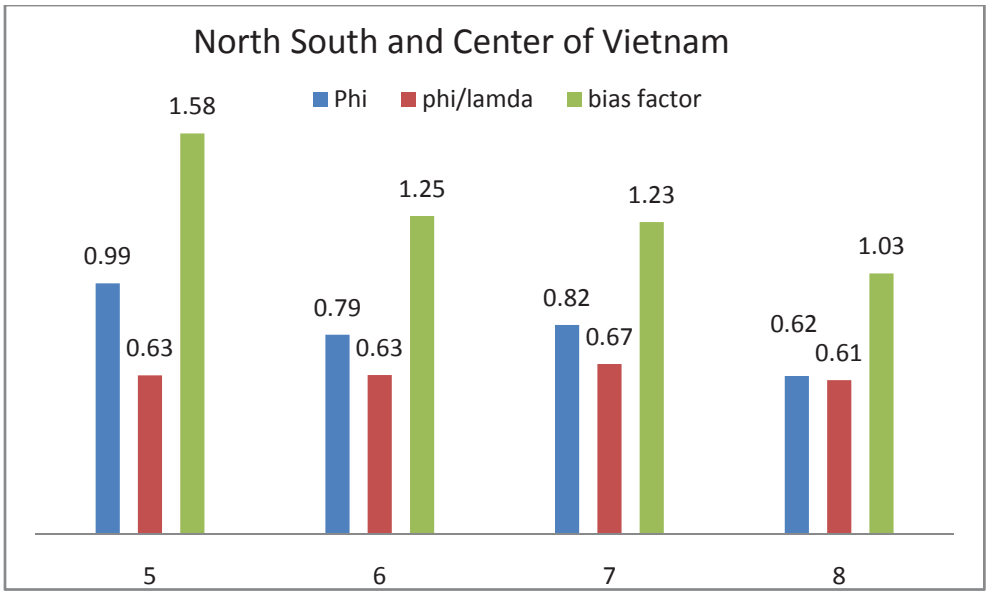


Figure 8.5a. Resistance factor, efficiency factor, equivalent factor of safety to ASD for drilled shaft using FHWA and Reese & Wright method with 0.5% D criterion settlement in North, Center and South of Vietnam

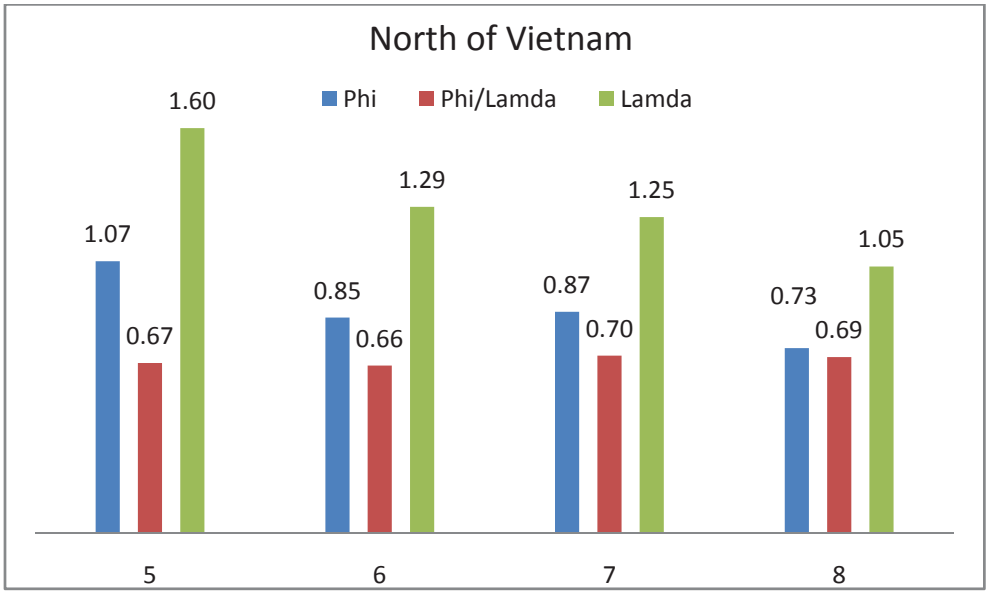


Figure 8.5b. Resistance factor, efficiency factor, equivalent factor of safety to ASD for drilled shaft using FHWA and Reese & Wright method with 0.5% D criterion settlement in North of Vietnam

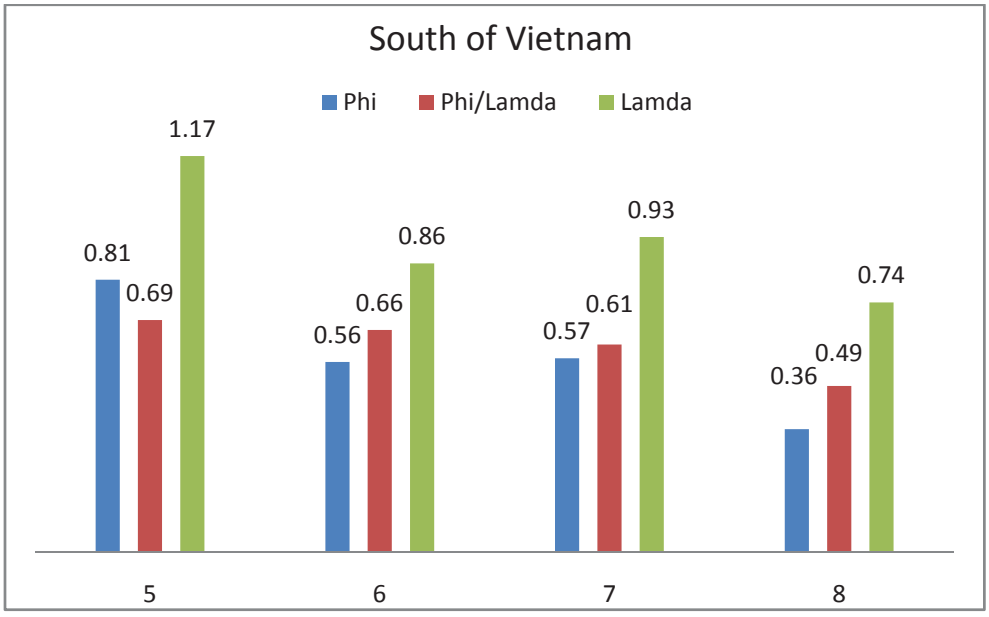


Figure 8.5c. Resistance factor, efficiency factor, equivalent factor of safety to ASD for drilled shaft using FHWA and Reese & Wright method with 0.5% D criterion settlement in South of Vietnam

8.5.2 Statistical sample size requirements for calibration the resistance factor for drilled shafts in Vietnam

To calibrate the resistance factor for drilled shafts requires collecting a certain number of the static load tests and soil profiles data. To find out how many data are needed for calibration the resistance factors, a number of bias factor data sets from 5 data to 80 data with increment of one data was randomly picked up 100 times from 92 data for drilled shafts and each time pick up the resistance factors was calibrated by using Monte-Carlo simulation method and mean value for each set of data was calculated. Figure 8.4, 8.5 and 8.6 show the number of data sets versus the resistance factor for drilled shafts using FHWA method with Su from Hara, Reese and Wright method with Su from Terzaghi and Peck and FHWA method with Su from Hara. From the result, a number of data is need for calibration for resistance factor is 30 data for drilled shafts since a number of data more than 30 data, the resistance factors calculated are almost the same.

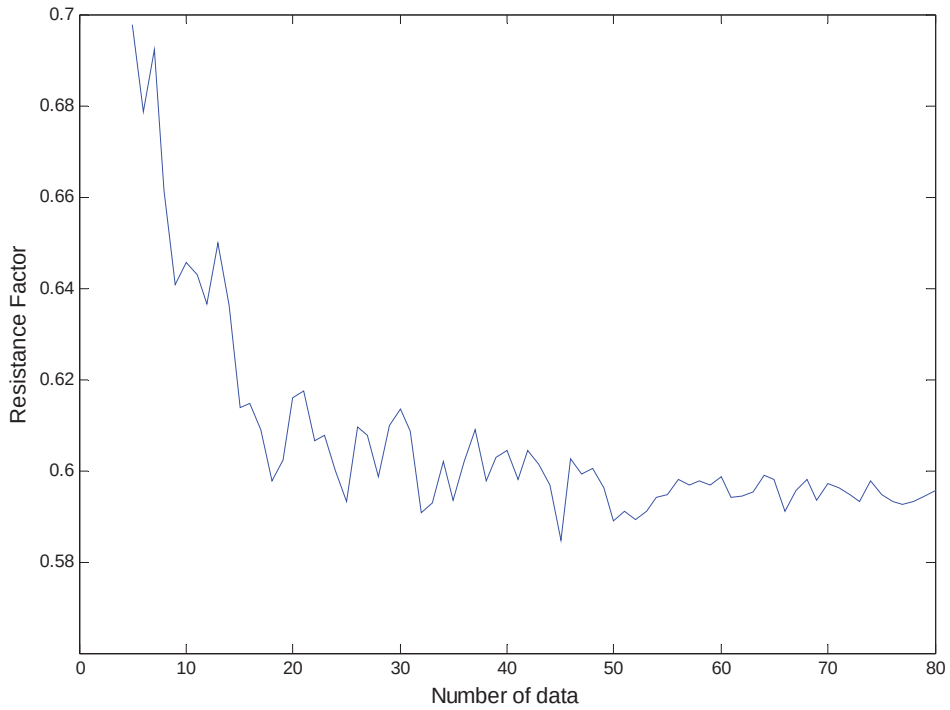


Fig 8.6 Number of data versus the resistance factor Φ with β_T =3.0 for drilled shaft (using the FHWA method and Su from Hara)

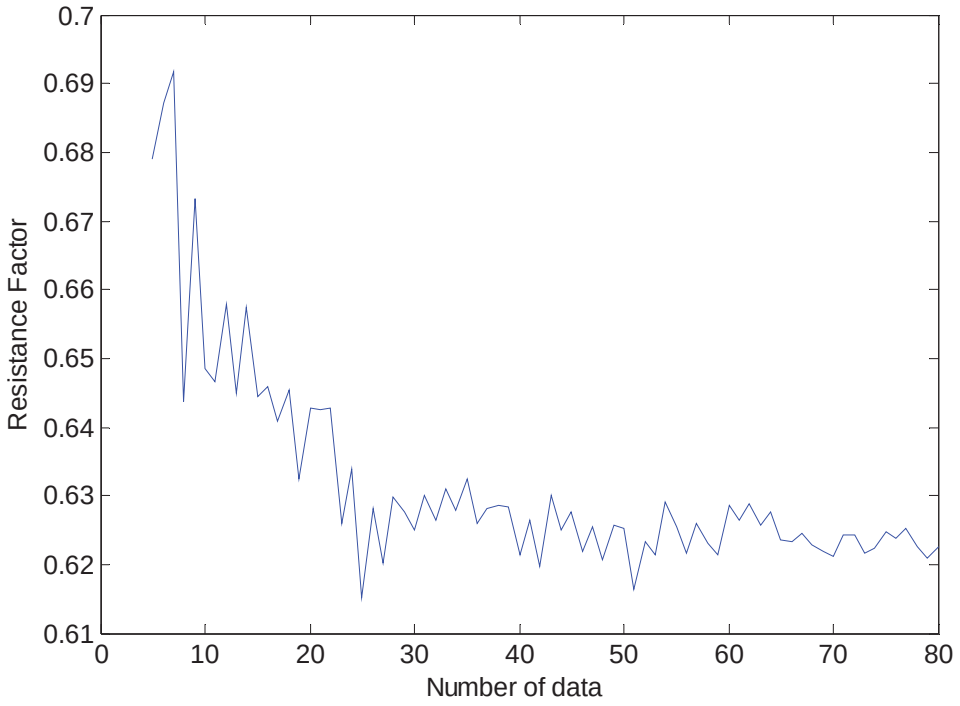


Fig 8.7 Number of data versus the resistance factor Φ with β_T =3.0 for drilled shaft using the Reese and Wright method (Su from Terzaghi and Peck)

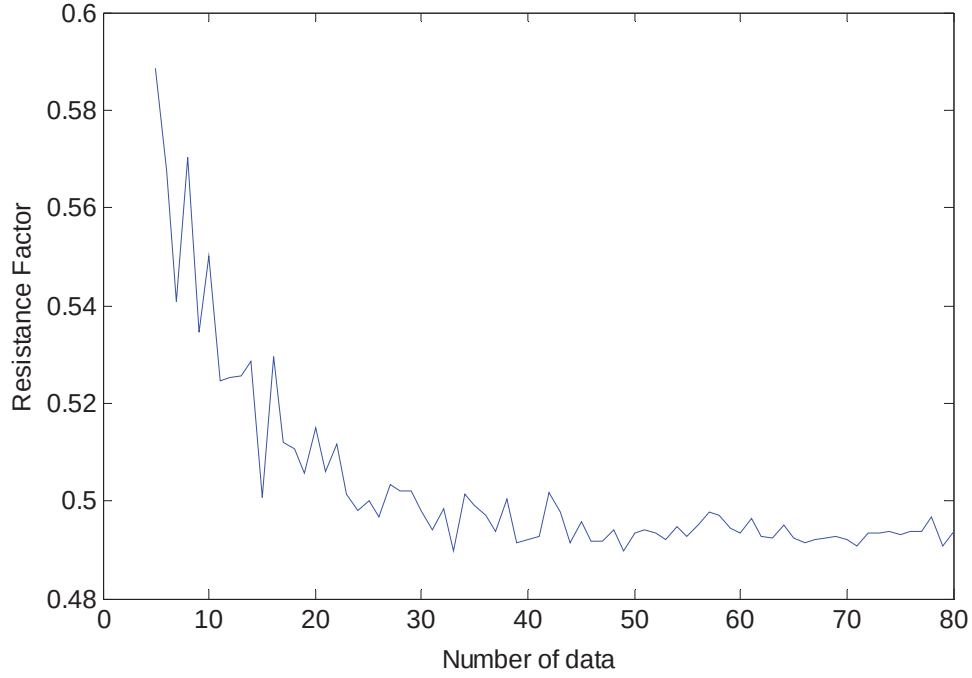


Fig 8.8 Number of data versus the resistance factor Φ with β_T =3.0 for drilled shaft using the Reese and Wright method (Su from Hara)

9. Conclusions and Recommendation

9.1 Summary of Research

Deep foundation data from different locations in NCHRP 507 report including 368 dynamic load tests in which 240 cases with end of driving (EOD) capacities and 128 cases with beginning of strike (BOR) capacities, and 131 static load tests for concrete piles with 19 cases in cohesive soils, 37 cases in cohesionless soils, and 85 cases in mixed soil. The U.S. database was used to calibrate the resistant factors of piles to examine the location dependency.

Eight different static analysis methods: α- Tomlinson, α-API, λ, β, Nordlund, Thurman, Meyerhof SPT, and the Shmertmann SPT method were used for calculating the design nominal capacity of driven piles. Resistance factor calibration was conducted based on the Vietnamese database includes 273 static load tests and soil profiles for driven piles in different soil types in North, Central and South Vietnam. Chin's method, Davisson's method, and the 1" settlement criterion were used in the interpretation of load test results for driven piles capacity in Vietnam. The FHWA method and Reese & Wright method were used to calculate the design nominal capacities of drilled shafts in Vietnam. The LRFD calibration was conducted based on 92 static load tests and soil profiles for drilled shafts in mixed soil in North, Central, and South Vietnam. The 1" and 0.5% of the pile diameter settlement criterions were used to determine the capacity of drilled shafts.

The calibration of resistance factors for deep foundations was performed using NCHRP 507 and Vietnamese database. Reliability based analyses using the First Order Second Moment (FOSM) method, the First Order Reliability Method (FORM), and the Monte Carlo (MC) simulation method were conducted to calibrate the resistance factors (Φ). Following ASSHTO 2012, the resistance

factors were evaluated at the target reliability index (β_T) of 2.33 for redundant piles (defined as 5 or more piles per pile cap (group)), which corresponds to a failure probability of 1%, and for the target reliability index (β_T) of 3.0 for non-redundant piles (defined as 4 or less piles per pile cap), which corresponds to a failure probability of 0.1%.

9.2 Major Outcomes and Conclusions

- Resistance factors are calibrated using three reliability analysis methods, including FOSM, FORM, and Monte Carlo Simulations. Of the three methods used the Monte Carlo and FORM methods yielded close results that encourage assurance. This being the case, the resistance factors given by the Monte Carlo simulations are chosen for the development of deep foundation design in this work.
- The resistance factors evaluated for PDA-CAPWAP data, using the NCHRP 507 data at EOD and BOR, vary with location.
- In general, the resistance factors found in this work for a specific/separate location are much different from the resistance factors given by the "lumped" or combined locations from the NCHRP 507 report and AASHTO specifications.
- When using semi-empirical methods and in-situ methods, the resistance factors for concrete pile design from Florida and Louisiana are only slightly different from the resistance factors recommended in NCHRP 507 report since most of the collected data is from Florida and Louisiana.
- For deep foundation design, no LFFD codes are available in Vietnam. This study provides the first development of resistant factors for driven piles and drilled shafts in Vietnam. The resistance factors evaluated in this study should be reliable

since they based on extensive collections of static load tests and soil profiles in North, South, and Central Vietnam. In chapter 7 the resistance factors were developed for driven pile design based upon detailed calibration with eight different methods for the capacities of piles in sand, clay, and mixed soil from different locations in Vietnam. The resistance factors for drilled shaft capacities may be found in chapter 8 and were developed based upon calibration with the FHWA and Reese & Wright methods in sand, clay and mixed Soil.

- The resistance factors, calibrated from the NCHRP 507 report and Vietnamese data, were determined to be strongly dependent upon design methods, deep foundation types, methods of exploration, testing of geo-materials, geo-material types, and geological formation.
- The regionally developed resistance factors were also compared to those provided in the design specifications to determine the percent increase or decrease in the factored capacity.

9.3 Recommendations

- AASHTO's resistance factors for application to all state DOTs or Vietnam will lead to under or over design of deep foundations. "So one size does not fit all" and different regions must have their own set of resistance factors.
- The resistance factors (Φ) for driven piles and drilled shafts in Vietnam, given in chapter 7 and 8, are recommended for design of deep foundations in Vietnam.

9.4 Recommendations for Future Research

- Continue to collect more static load tests (preferably with strain gauge instrumentation), PDA, and soil profiles for driven piles and drilled shafts in Central and South Vietnam in cohesive and cohesionless soil.
- Use the collected load test and soil exploration data to validate a well verified finite element analysis (FEA) program that may be used to study the load-deformation behavior of deep foundations.
- Develop/calibrate resistance factors for deep foundation service limit states using both the finite element method (FEM) and the collected deep foundation test data for both vertical and horizontal displacements.

APPENDIX A
Calibration Resistance Factor by Using FORM for Driven Pile using CAPWAP Method

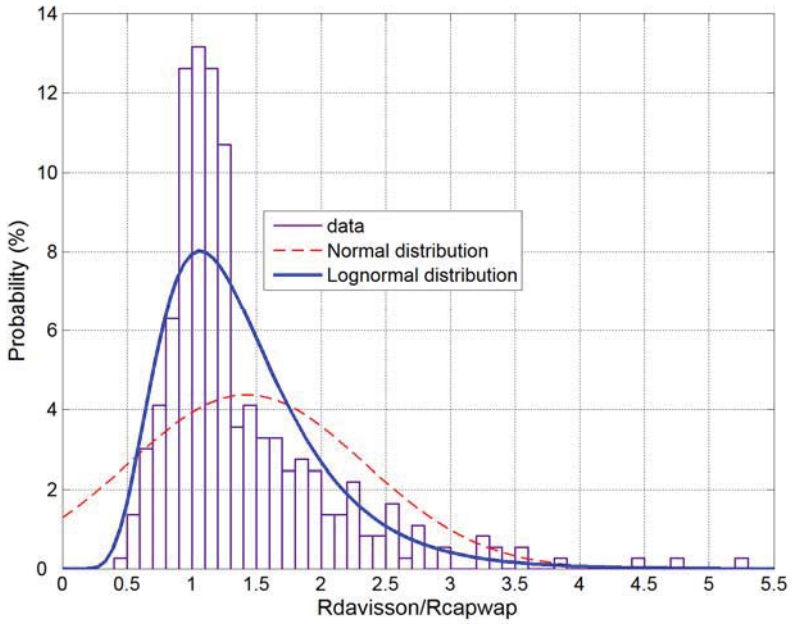


Figure A-1a Frequency Distribution for All 365 CAPWAP (BOR+EOD) Cases

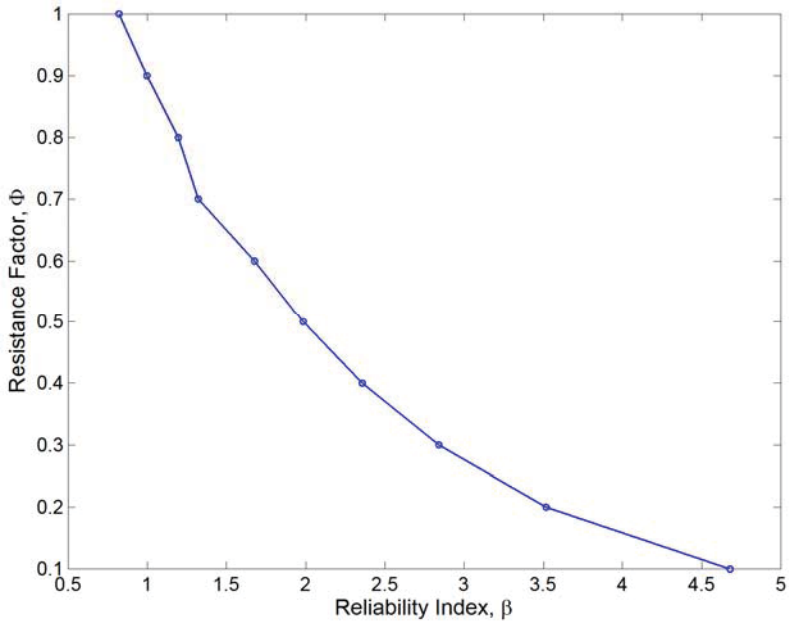


Figure A-1b Resistance Factor Calibration from 365 CAPWAP (BOR+EOD) Case

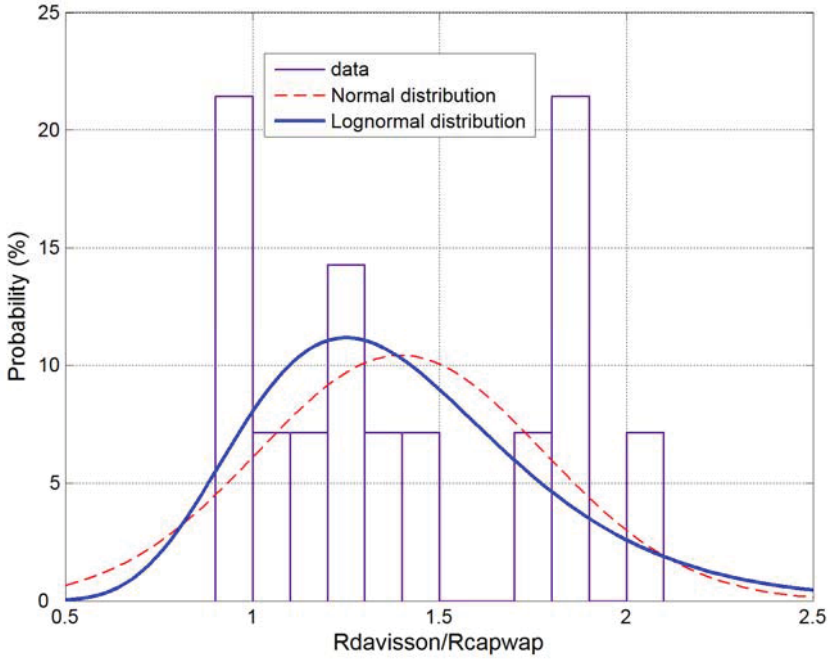


Figure A-2a Frequency Distribution for 14 CAPWAP (BOR+EOD) Cases in Alabama

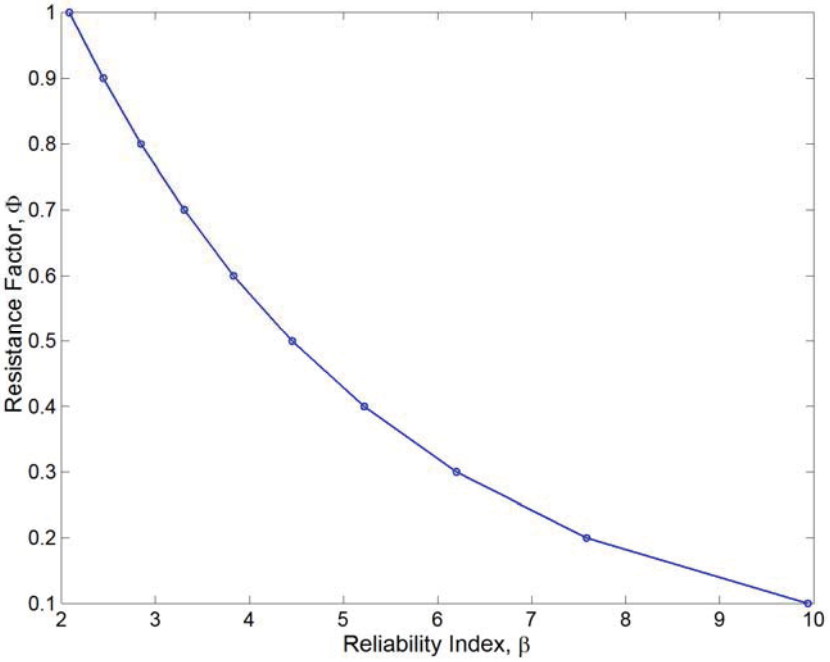


Figure A-2b Resistance Factor Calibration from 14 CAPWAP (BOR+EOD) Cases in Alabama

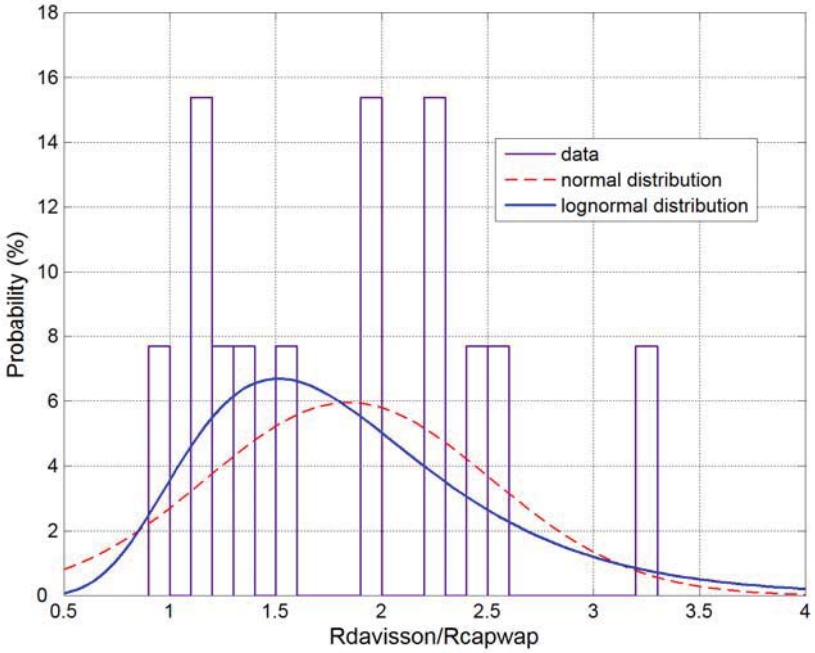


Figure A-3a Frequency Distribution for 13 CAPWAP (BOR+EOD) Cases in California

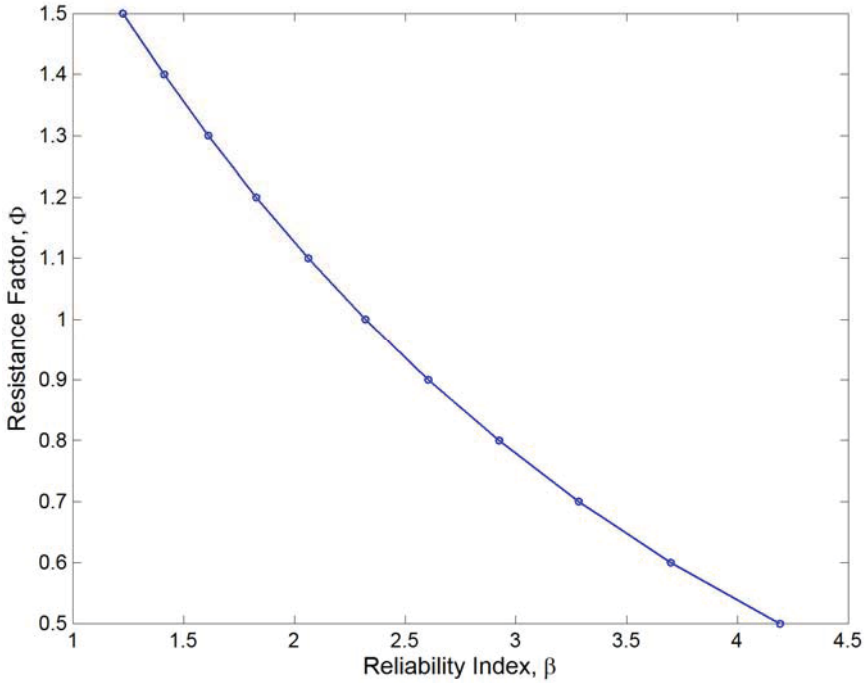


Figure A-3b Resistance Factor Calibration from 13 CAPWAP (BOR+EOD) Cases in California

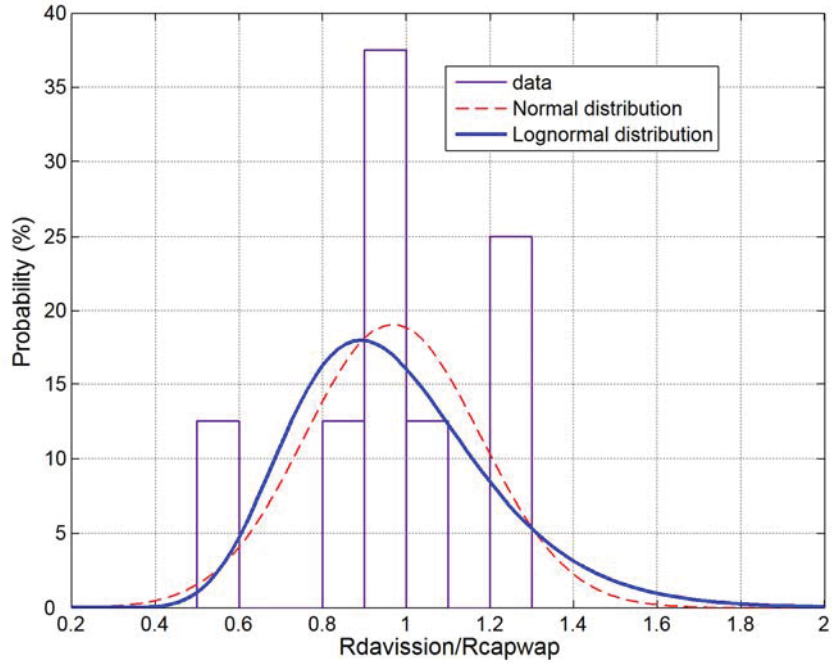


Figure A-4a Frequency Distribution for 8 CAPWAP (BOR+EOD) Cases in Canada

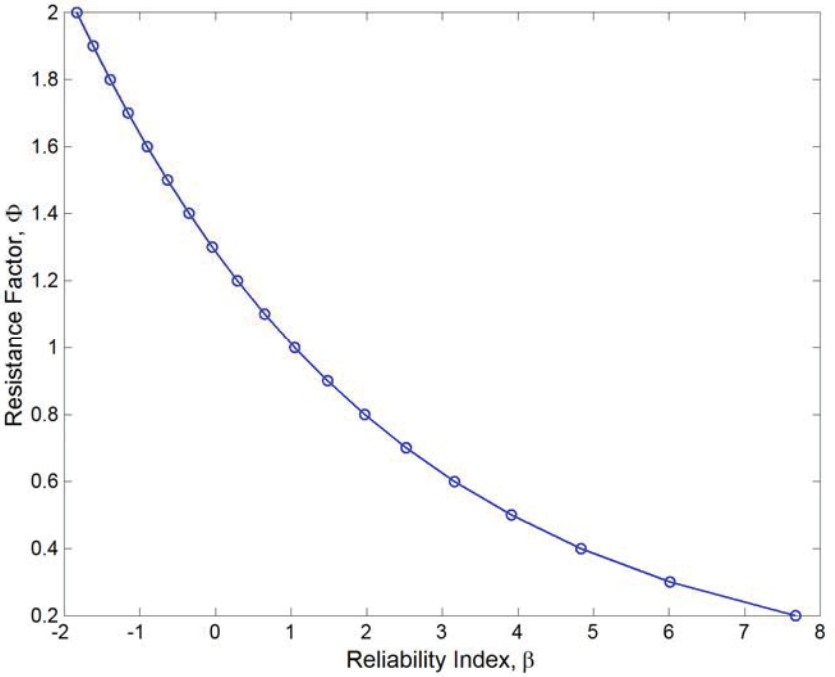


Figure A-4b Resistance Factor Calibration from 8 CAPWAP (BOR+EOD) Cases in Canada

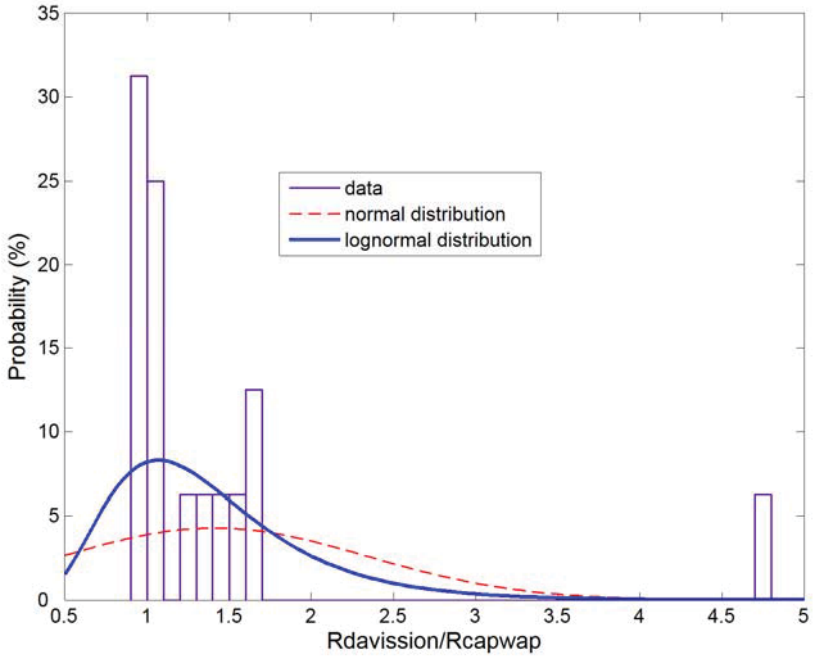


Figure A-5a Frequency Distribution for 16 CAPWAP (BOR+EOD) Cases in S Carolina

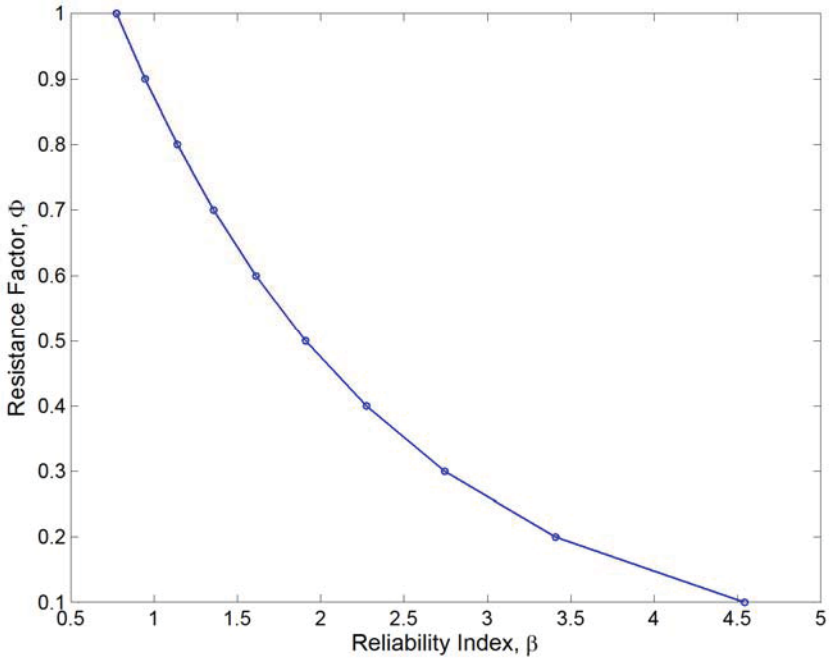


Figure A-5b Resistance Factor Calibration from 16 CAPWAP (BOR+EOD) Cases in S Carolina

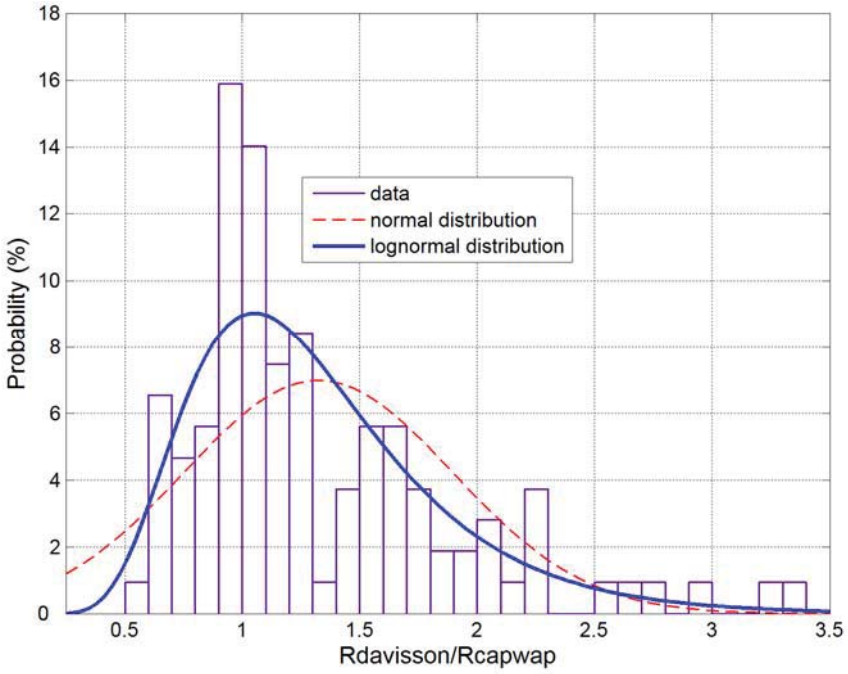


Figure A-6a Frequency Distribution for 107 CAPWAP (BOR+EOD) Pile-Cases in Florida

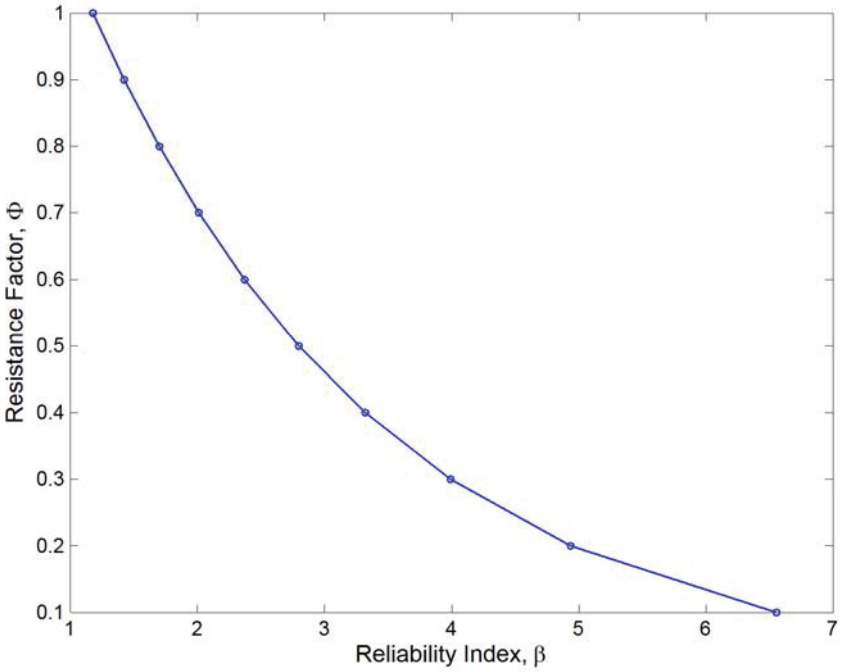


Figure A-6b Resistance Factor Calibration from 107 CAPWAP (BOR+EOD) pile-cases in Florida

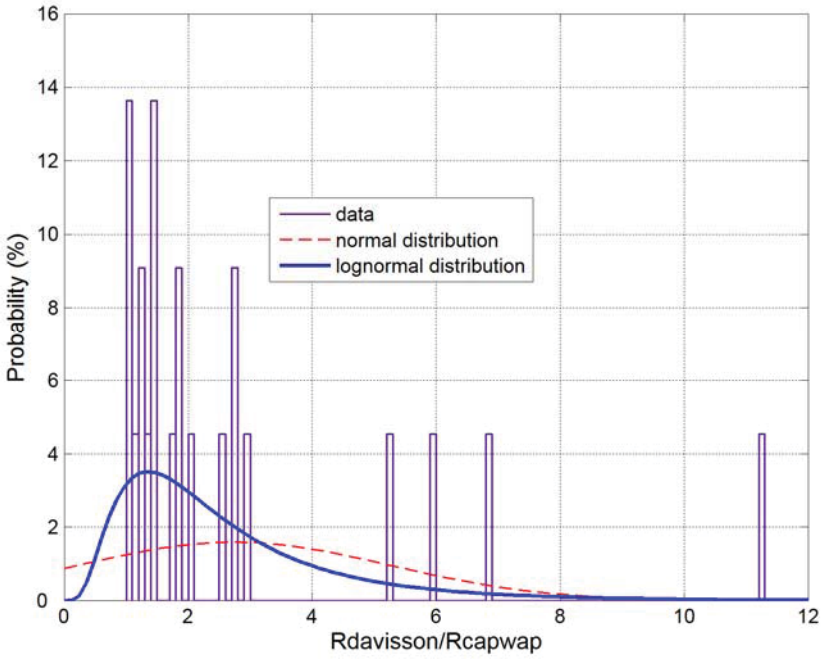


Figure A-7a Frequency Distribution for
22 CAPWAP (BOR+EOD) Cases in Louisiana

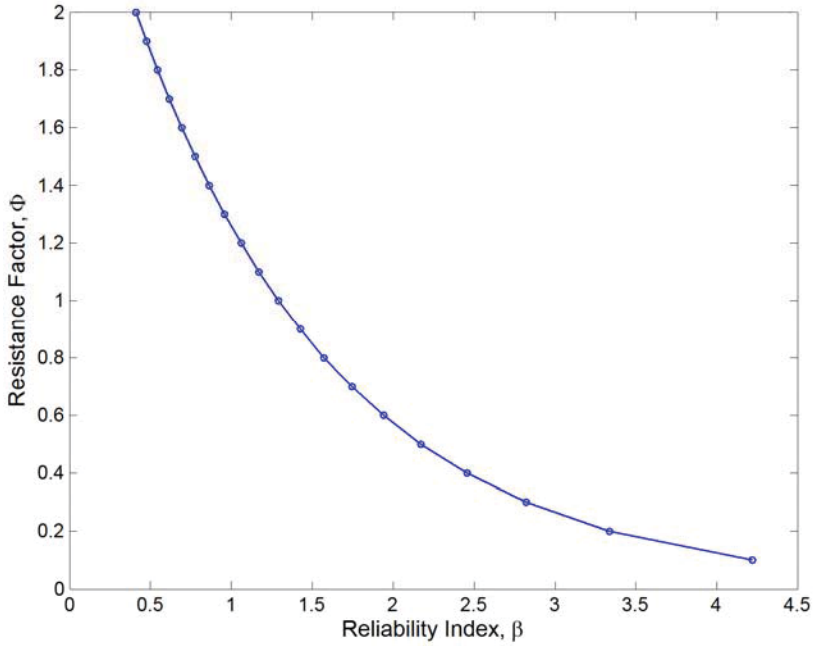


Figure A-7b Resistance Factor Calibration from
22 CAPWAP (BOR+EOD) Cases in Louisiana

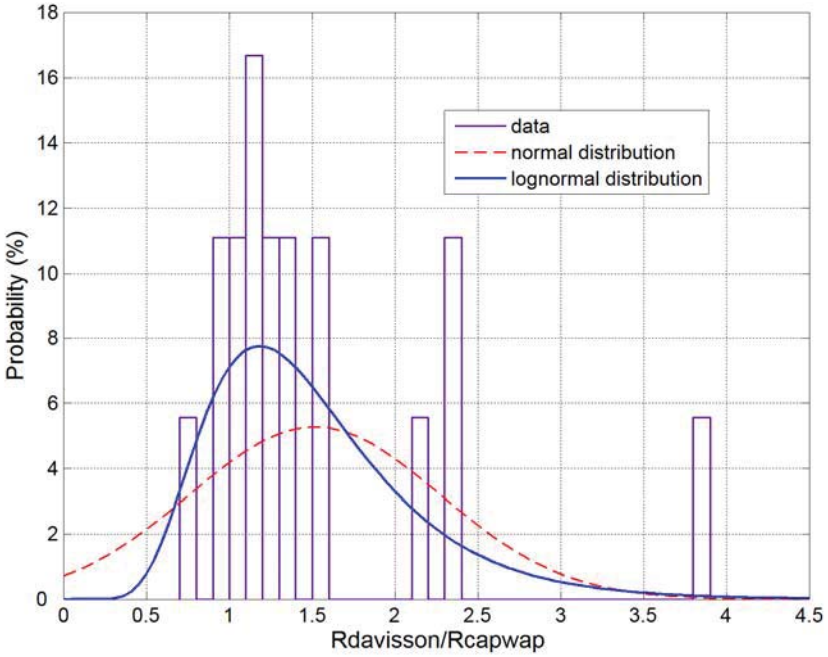


Figure A-8a Frequency Distribution for
17 CAPWAP (BOR+EOD) Cases in Massachusetts

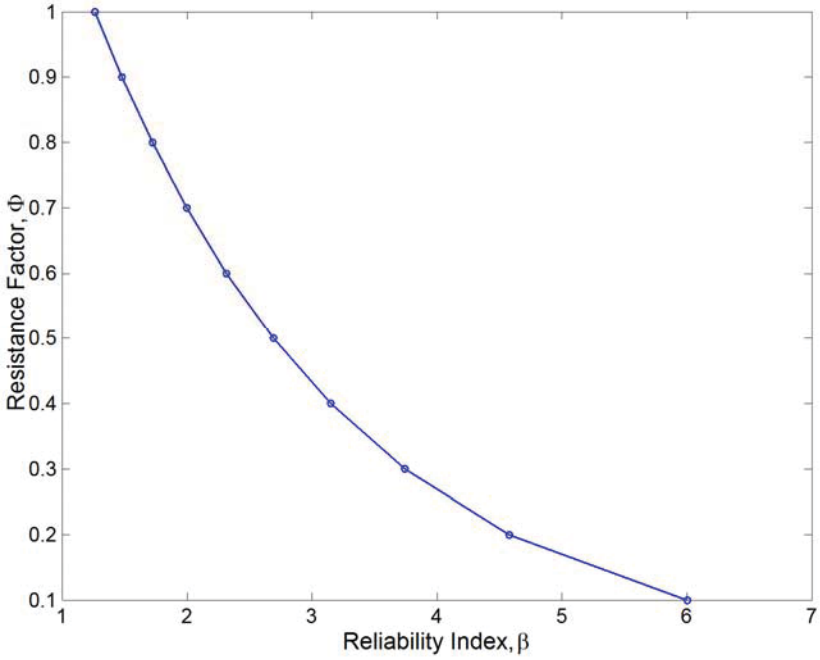


Figure A-8b Resistance Factor Calibration from
17 CAPWAP (BOR+EOD) Cases in Massachusetts

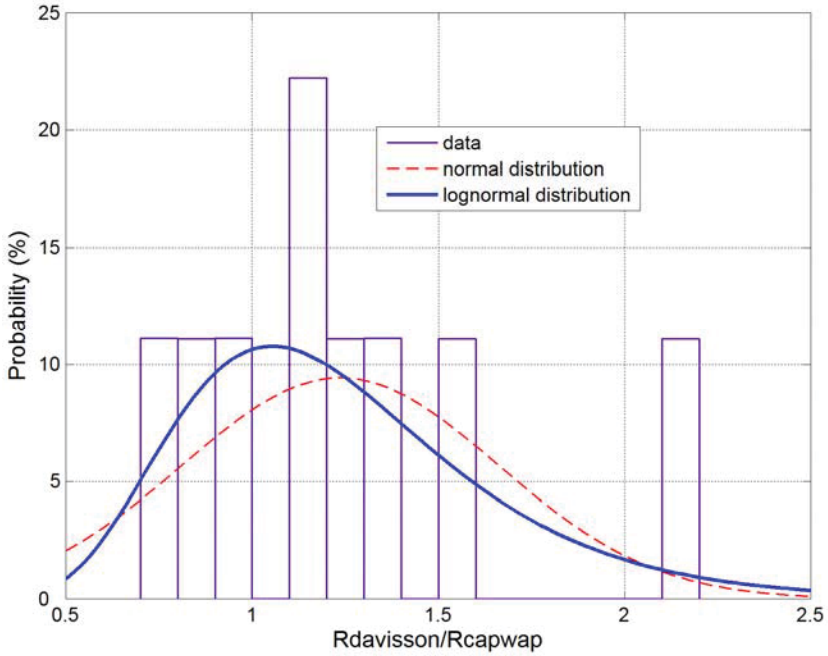


Figure A-9a Frequency Distribution for
9 CAPWAP (BOR+EOD) Cases in Nebraska

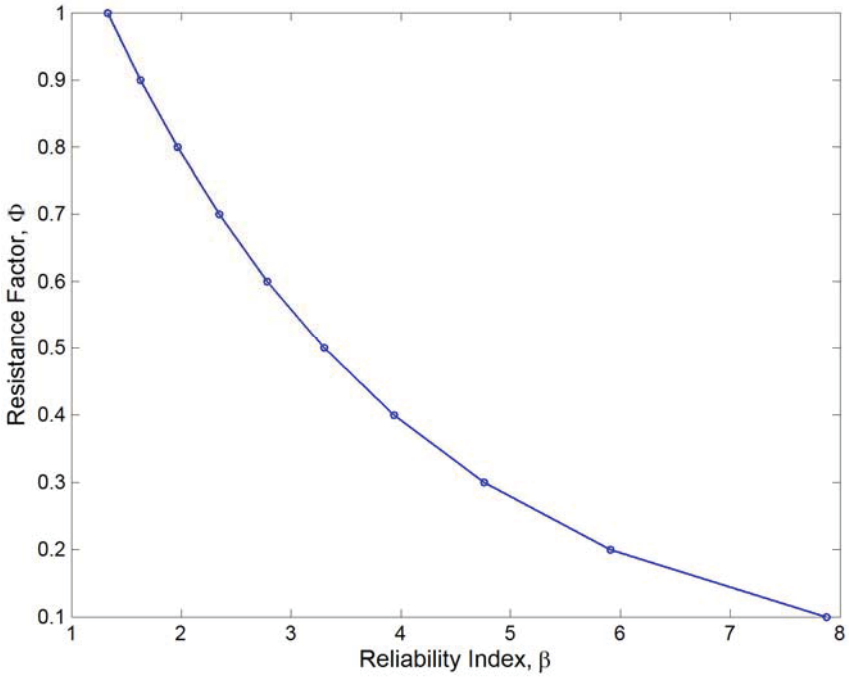


Figure A-9b Resistance Factor Calibration from
9 CAPWAP (BOR+EOD) Cases in Nebraska

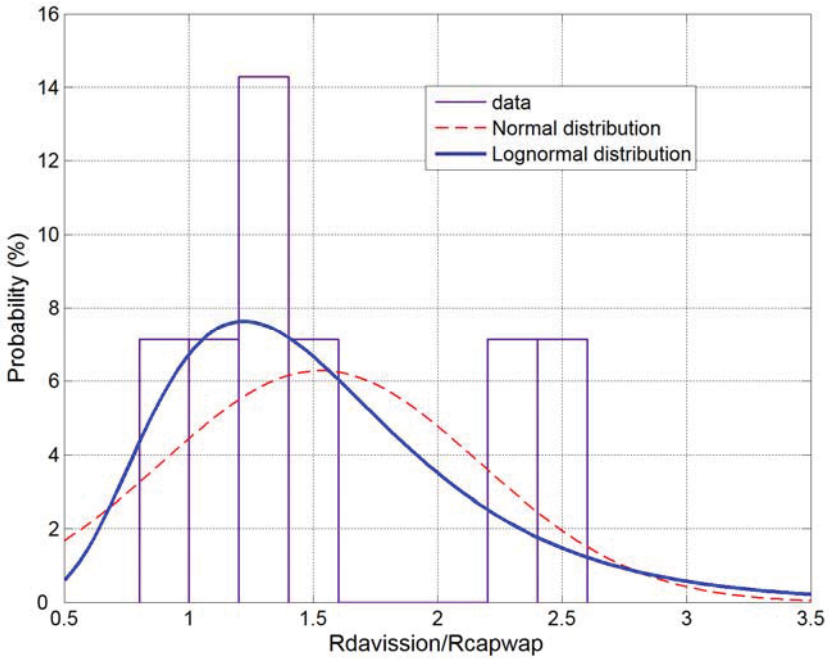


Figure A-10a Frequency Distribution for
7 CAPWAP (BOR+EOD) Cases in Oklahoma

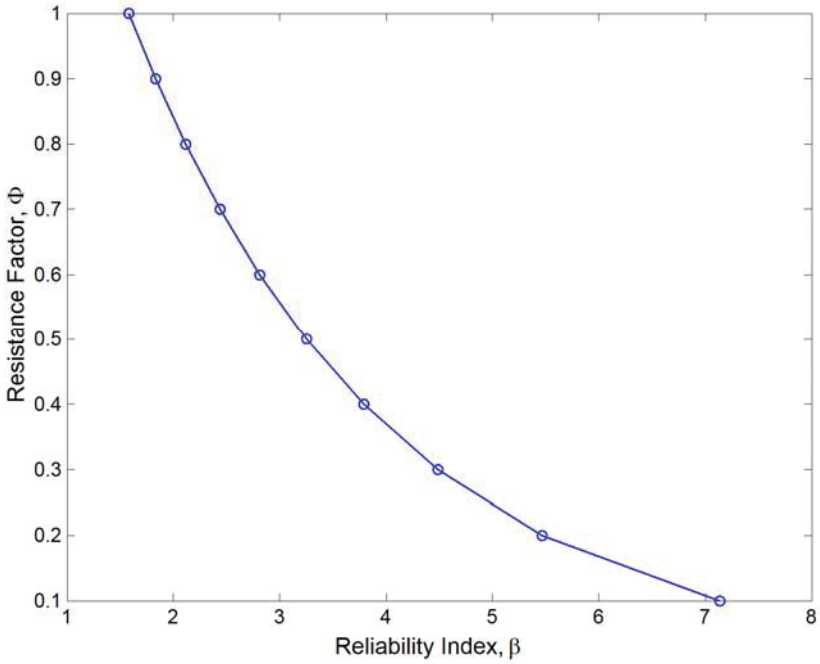


Figure A-10b Resistance Factor Calibration from
7 CAPWAP (BOR+EOD) Cases in Oklahoma

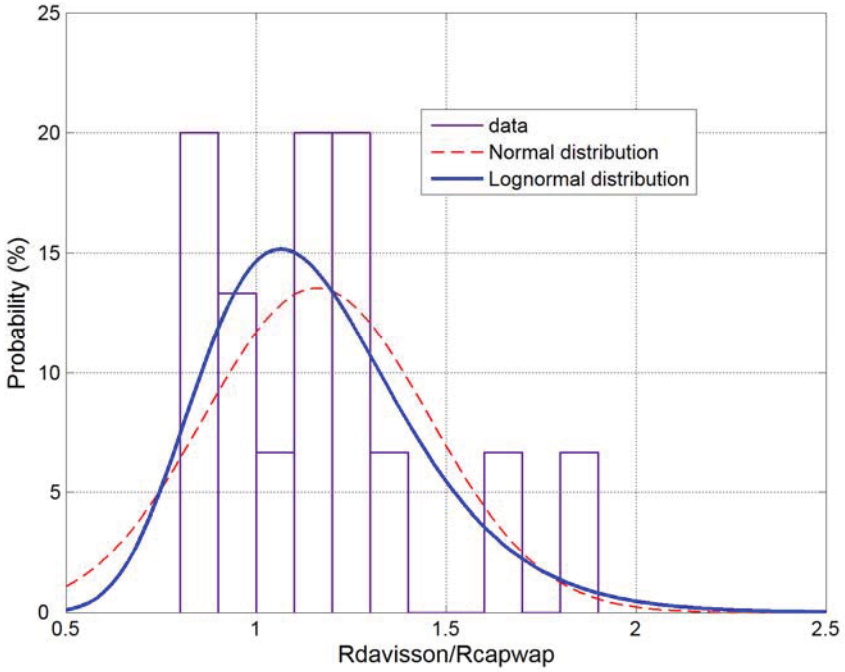


Figure A-11a Frequency distribution for 15 CAPWAP (BOR+EOD) Cases in Ortanrio

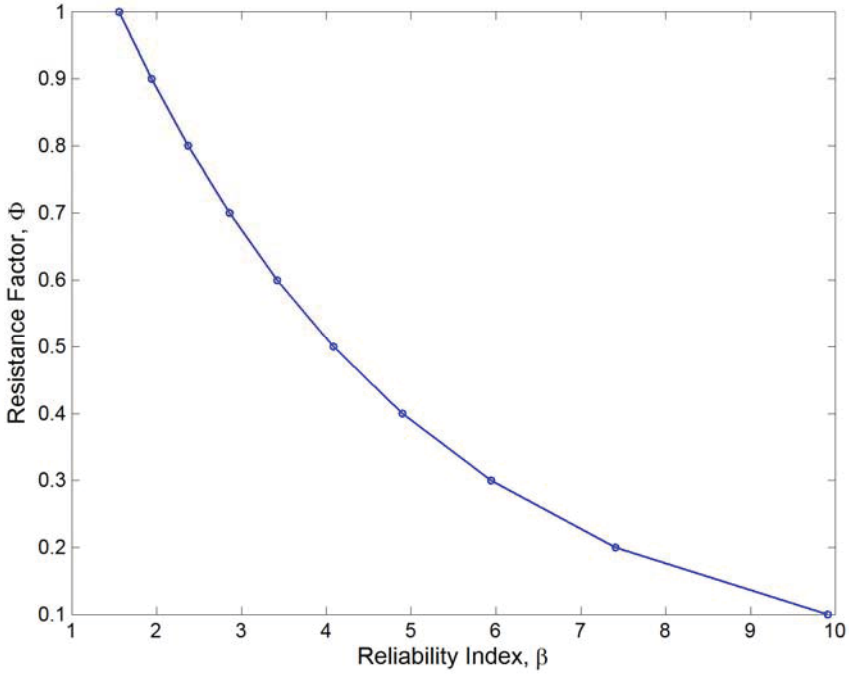


Figure A-11b Resistance Factor Calibration from
15 CAPWAP (BOR+EOD) Cases in Ortanrio

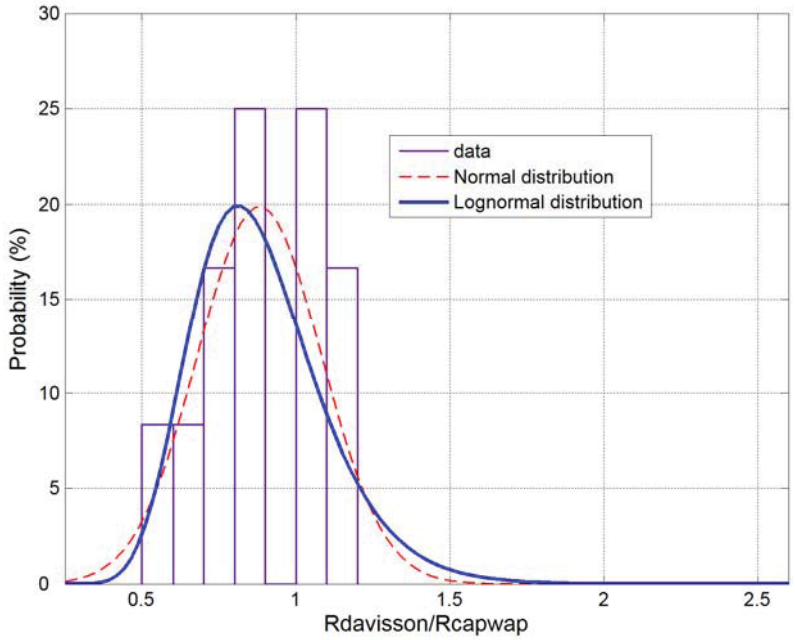


Figure A-12a Frequency Distribution for
12 CAPWAP (BOR+EOD) Cases in Pennsylvania

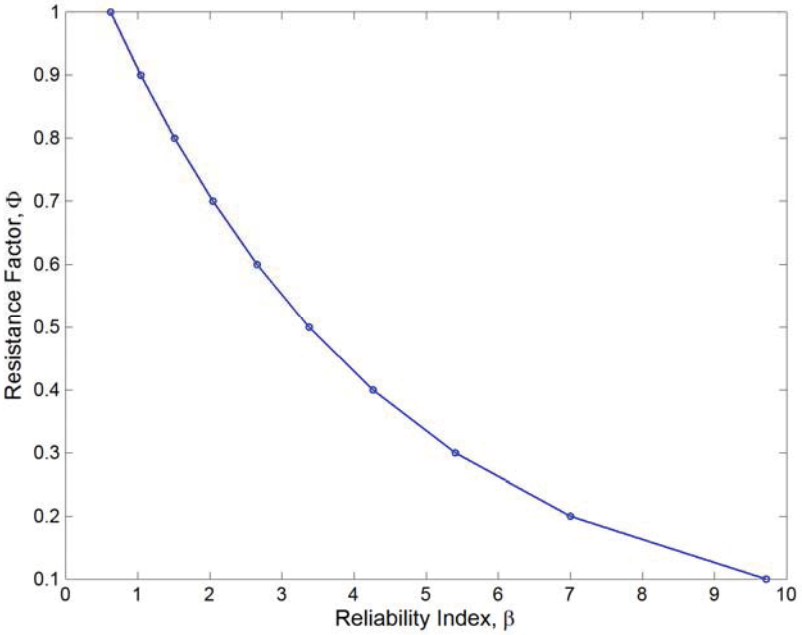


Figure A-12b Resistance Factor Calibration from
12 CAPWAP Cases in Pennsylvania

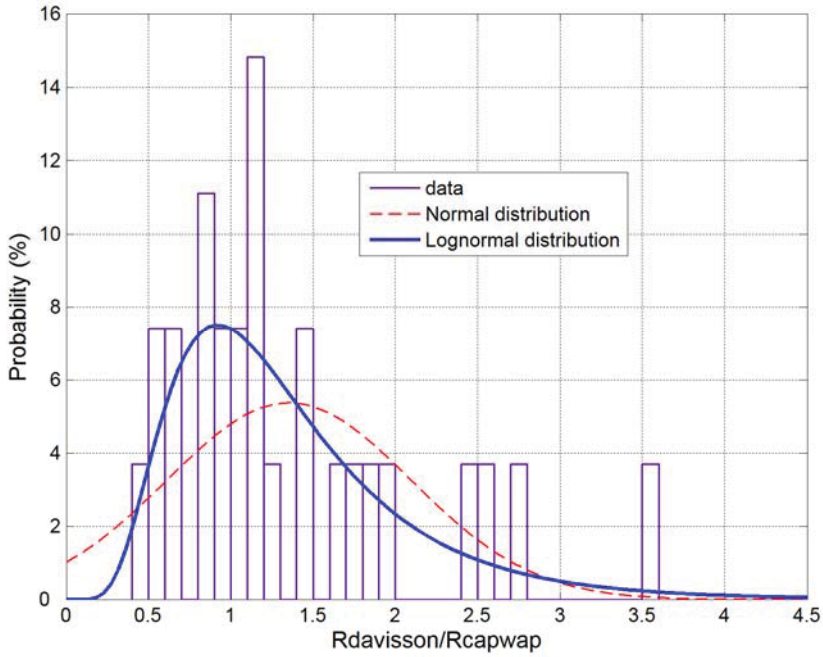


Figure A-13a Frequency Distribution for
27 CAPWAP (BOR+EOD) Cases in Wisconsin

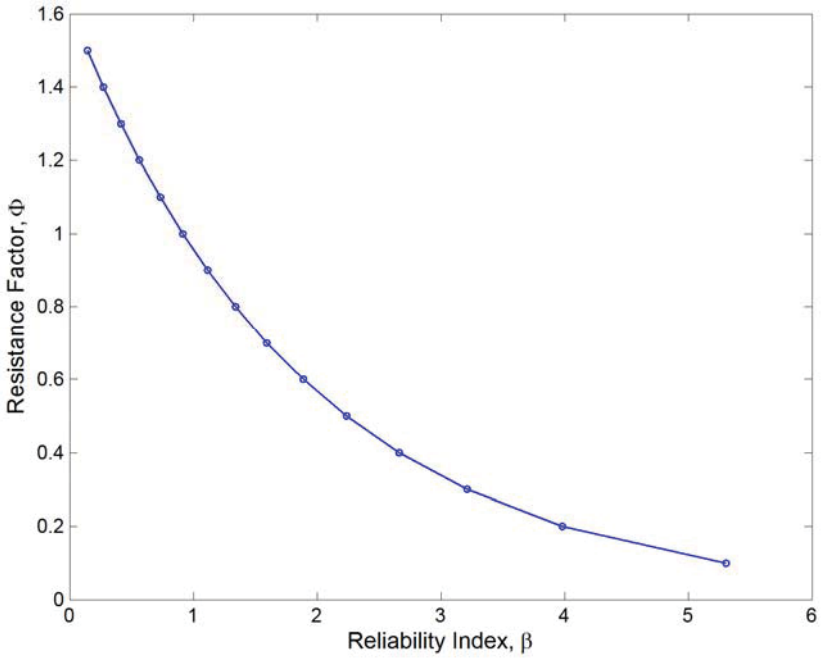


Figure A-13b Resistance Factor Calibration from
27 CAPWAP (BOR+EOD) Cases in Wisconsin

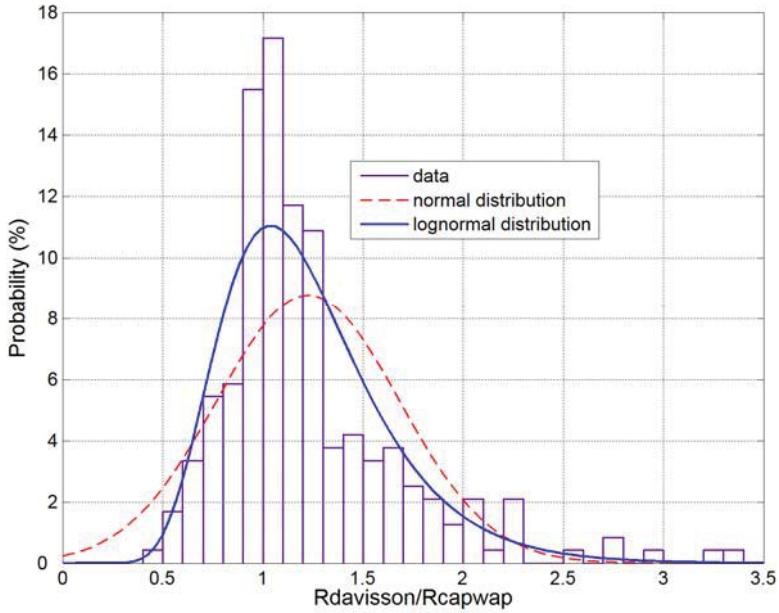


Figure A-14a Frequency Distribution for All 240 CAPWAP (BOR) Cases

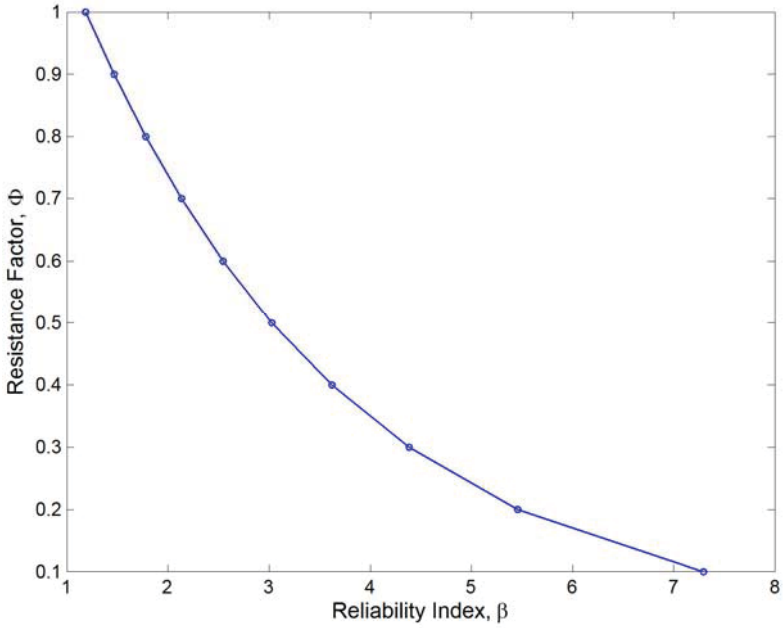


Figure A-14b Resistance Factor Calibration from
240 CAPWAP (BOR) Cases

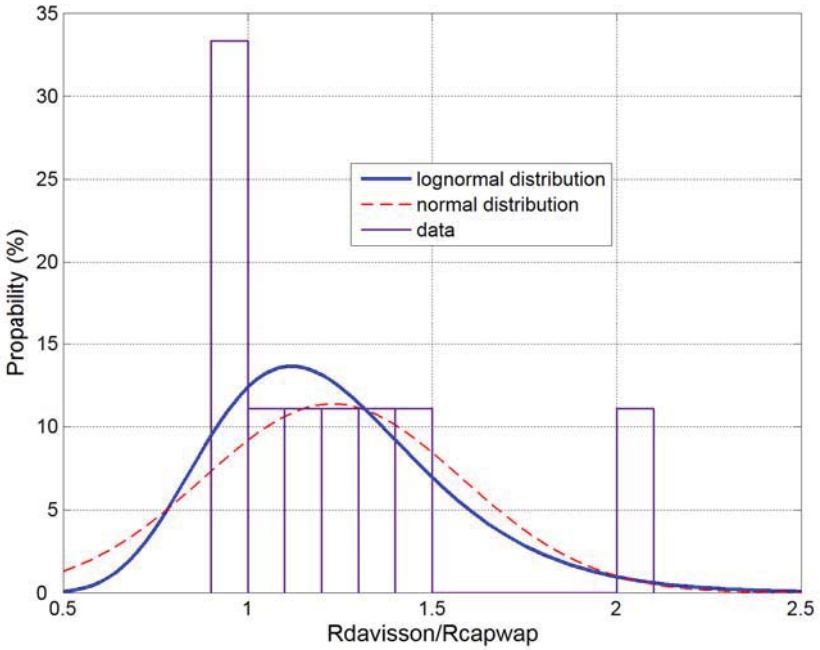


Figure A-15a Frequency Distribution for 9 CAPWAP (BOR) Cases in Alabama

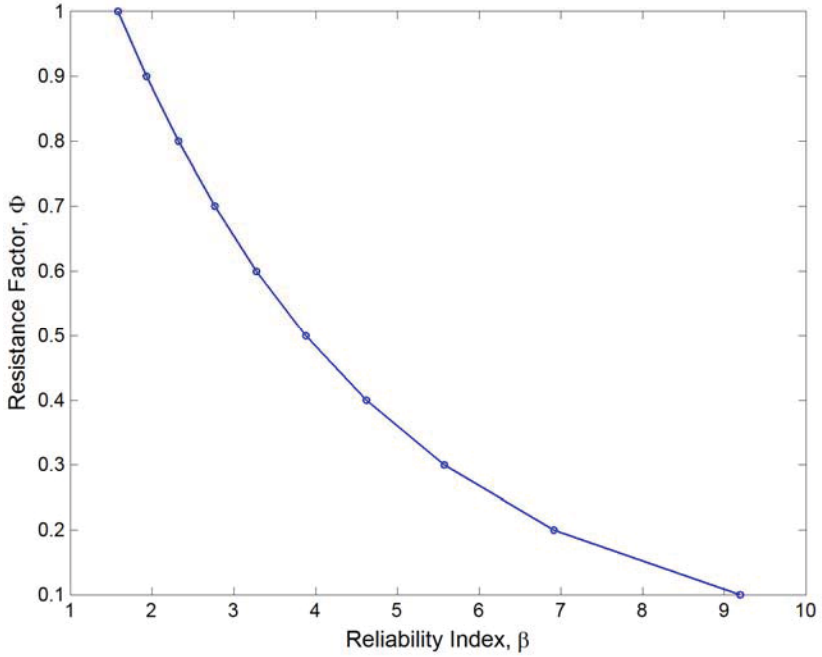


Figure A-15b Resistance Factor Calibration from
9 CAPWAP (BOR) Cases in Alabama

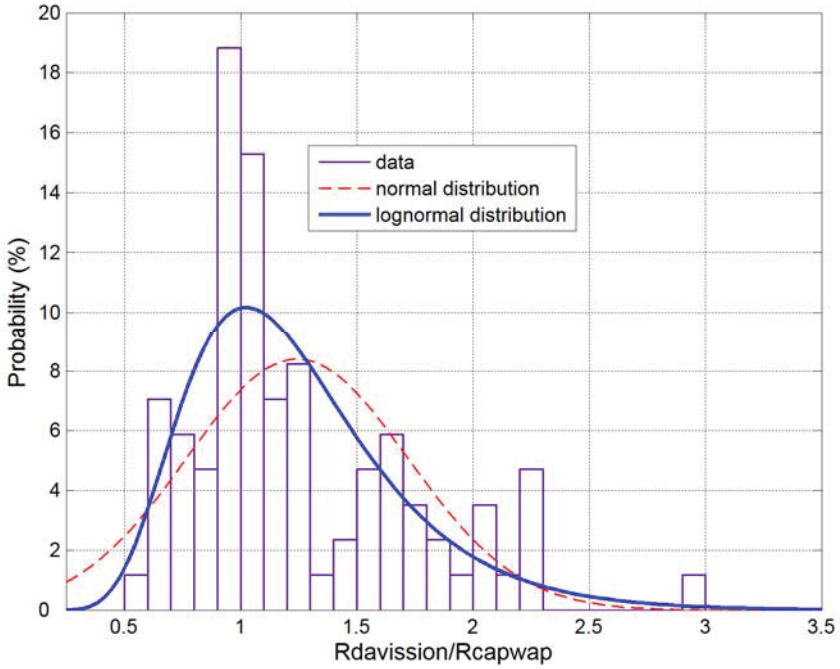


Figure A-16a Frequency Distribution for 85 CAPWAP (BOR) Cases in Florida

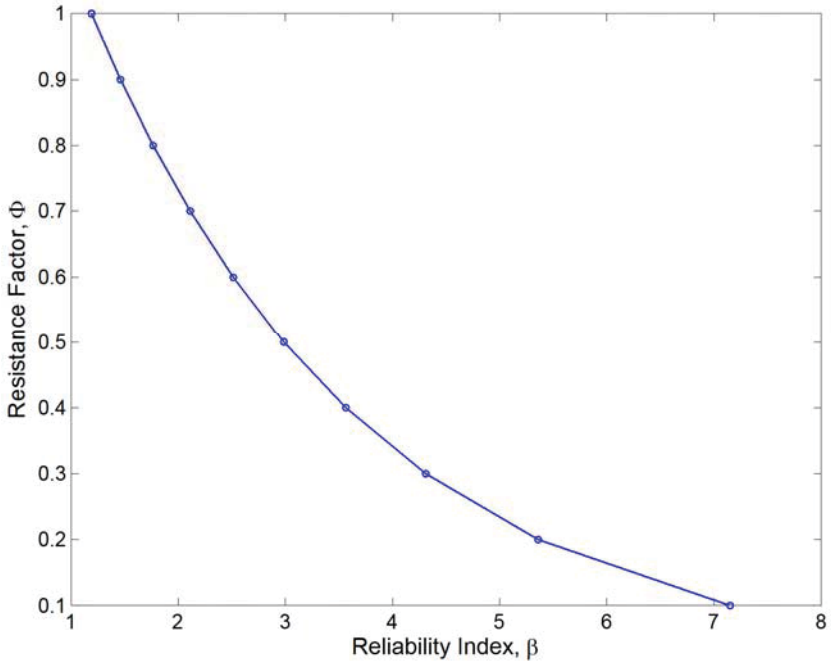


Figure A-16b Resistance Factor Calibration from
85 CAPWAP (BOR) Cases in Florida

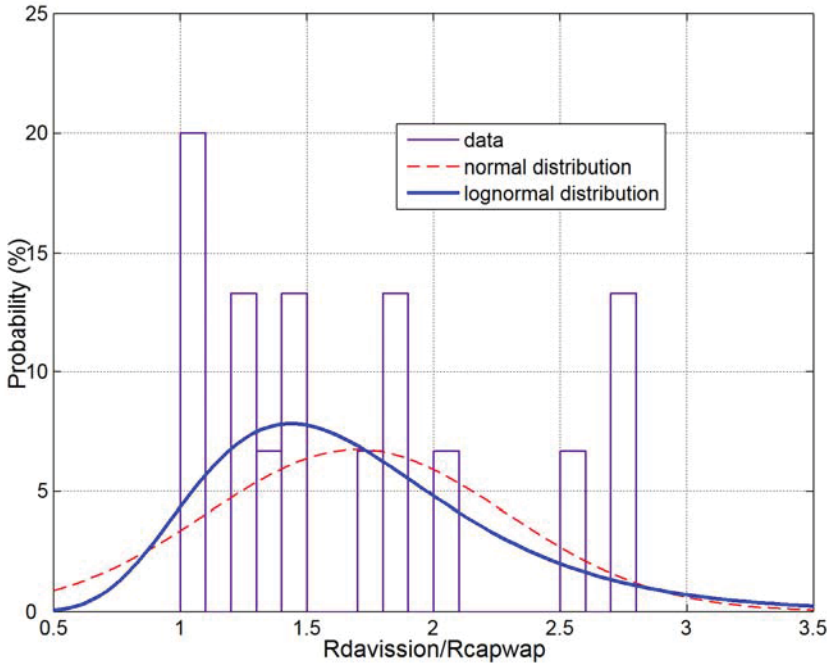


Figure A-17a Frequency Distribution for 15 CAPWAP (BOR) Cases in Louisiana

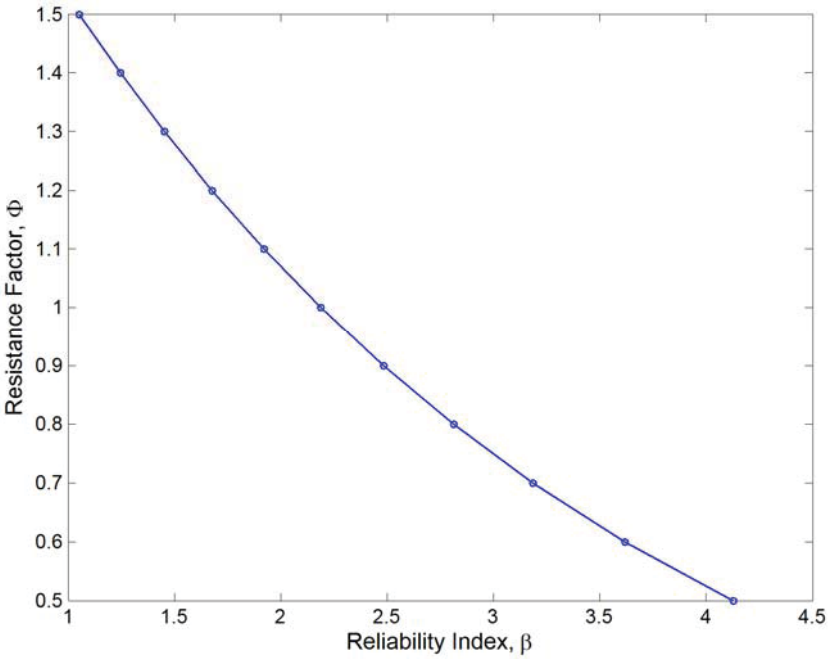


Figure A-17b Resistance Factor Calibration from
15 CAPWAP (BOR) Cases in Louisiana

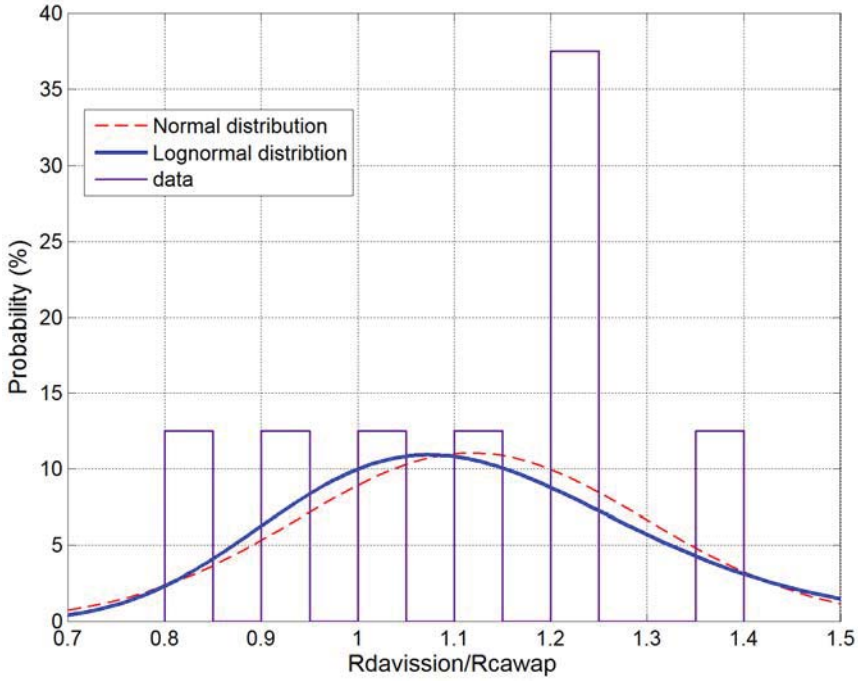


Figure A-18a Frequency Distribution for 15 CAPWAP (BOR) Cases in Ontario

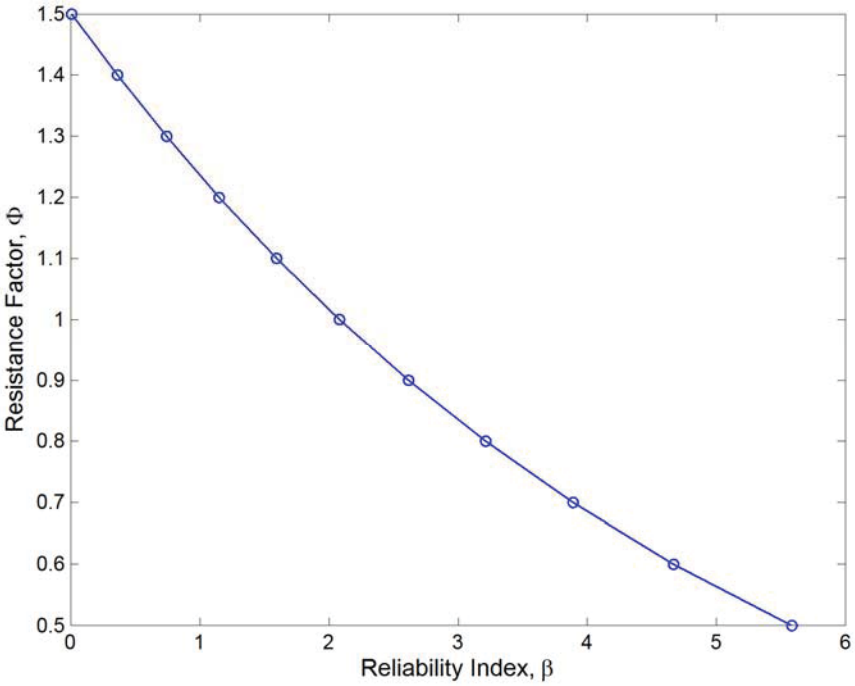


Figure A-18b Resistance Factor Calibration from
15 CAPWAP (BOR) Cases in Ontario

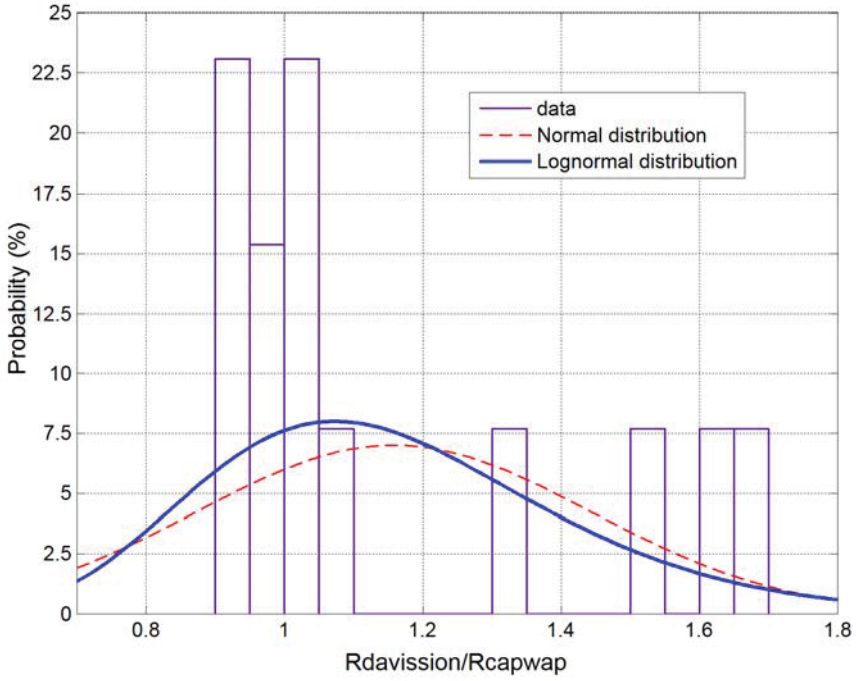


Figure A-19a Frequency Distribution for 13 CAPWAP (BOR) Cases in S. Carolina

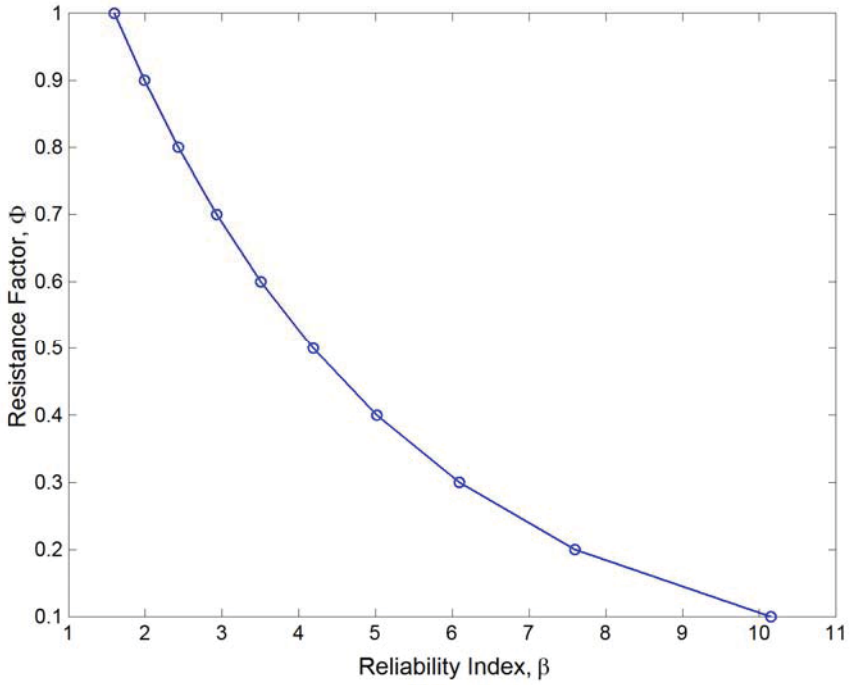


Figure A-19b Resistance Factor Calibration from
13 CAPWAP (BOR) Cases in S. Carolina

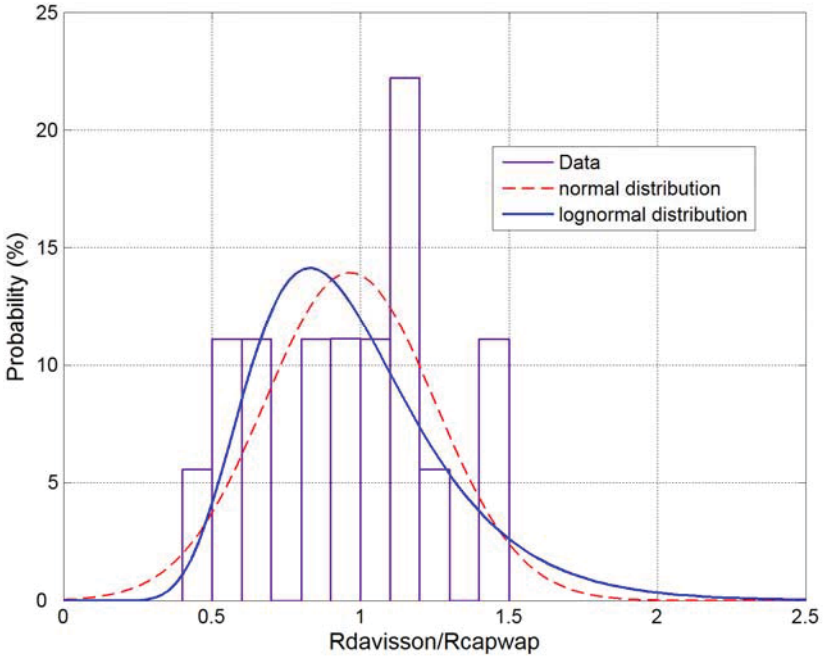


Figure A-20a Frequency Distribution for 15 CAPWAP (BOR) Cases in Wisconsin

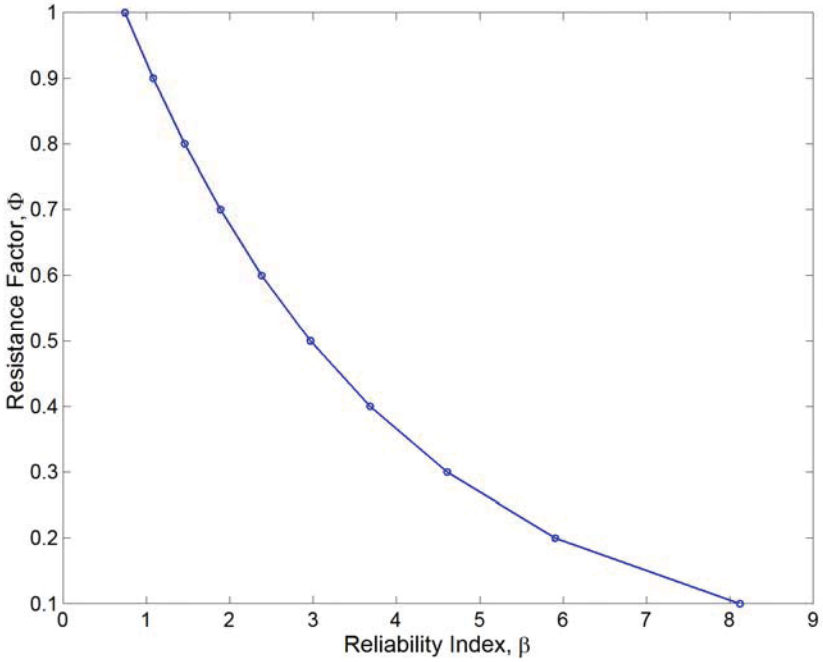


Figure A-20b Resistance Factor Calibration from
15 CAPWAP-BOR Cases in Wisconsin

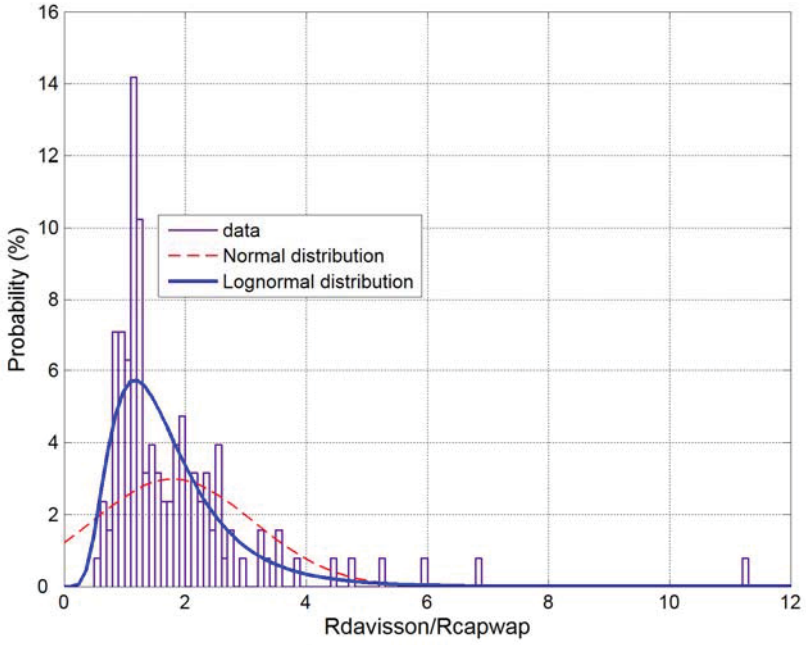


Figure A-21a Frequency Distribution for All 128 CAPWAP (EOD) Cases

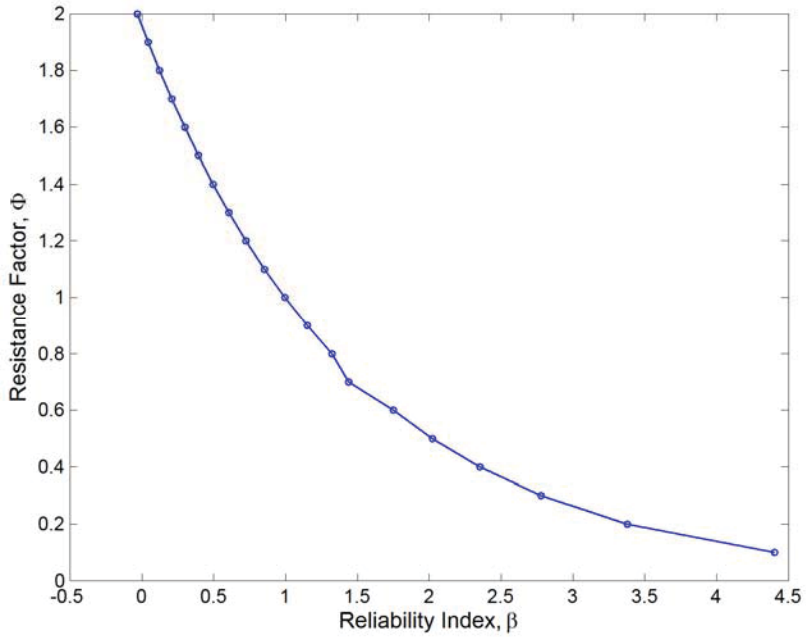


Figure A-21b Resistance Factor Calibration from
128 CAPWAP (EOD) Cases

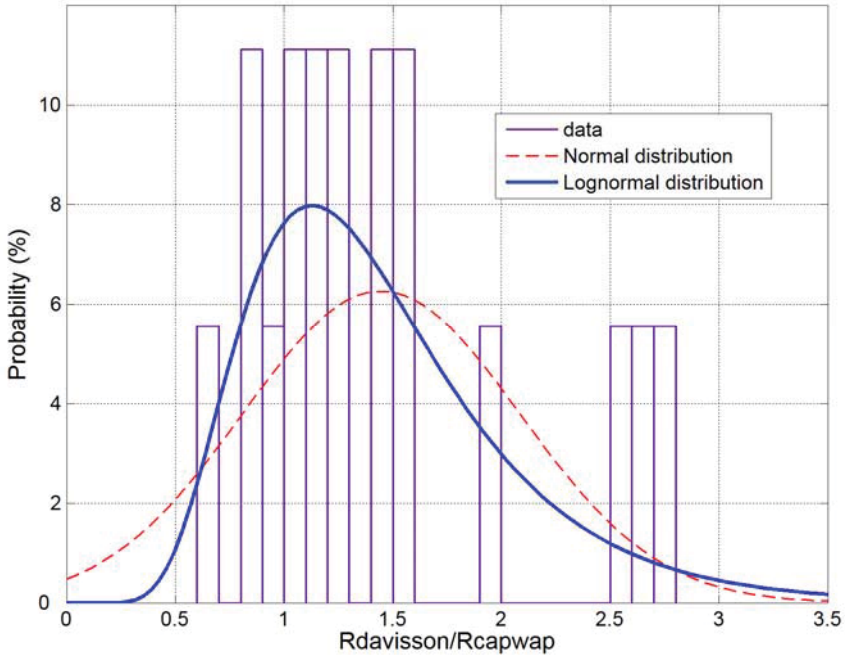


Figure A-22a Frequency Distribution for 20 CAPWAP-EOD Cases in Florida

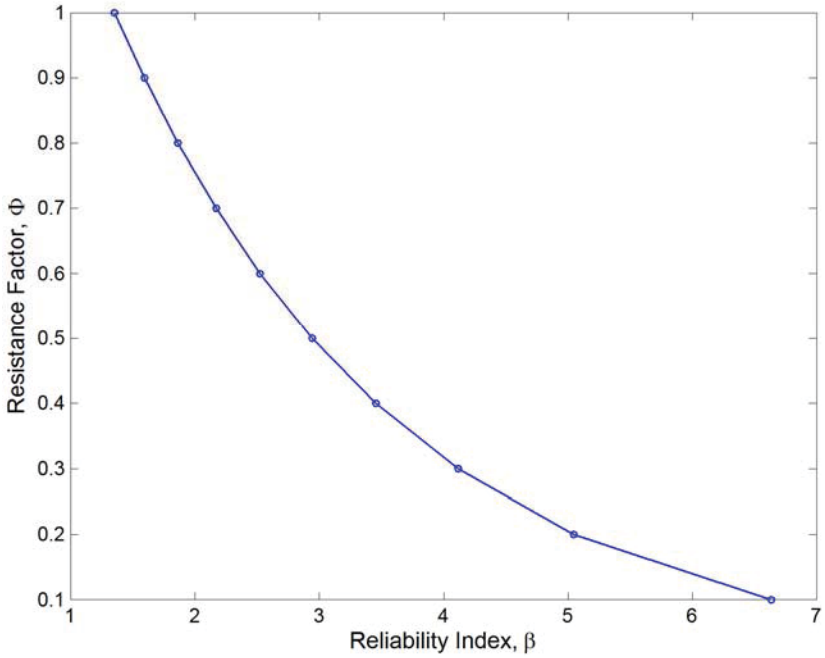


Figure A-22b Resistance Factor Calibration from
20 CAPWAP-EOD Pile in Florida

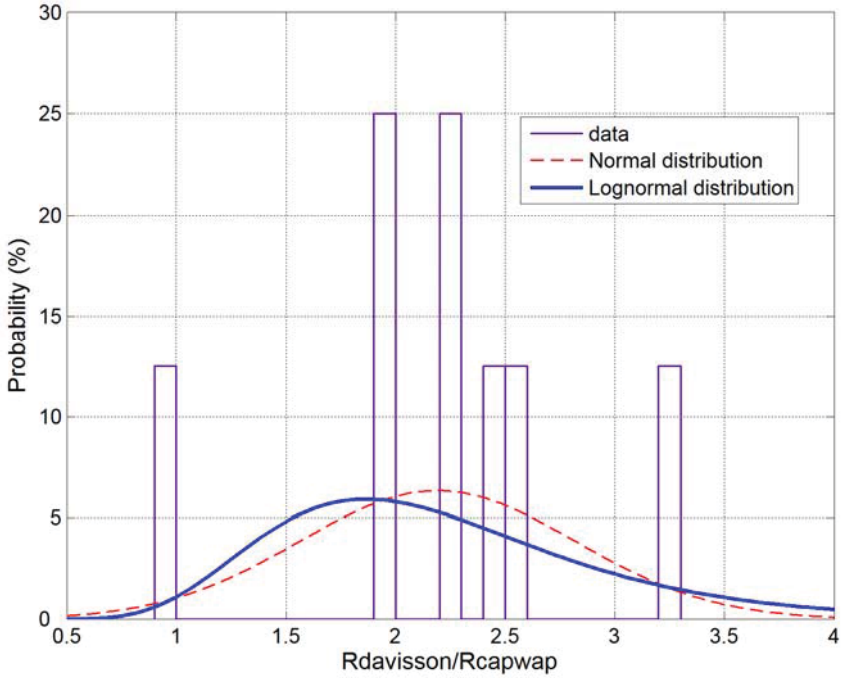


Figure A-23a Frequency Distribution for 8 CAPWAP-EOD Cases in California

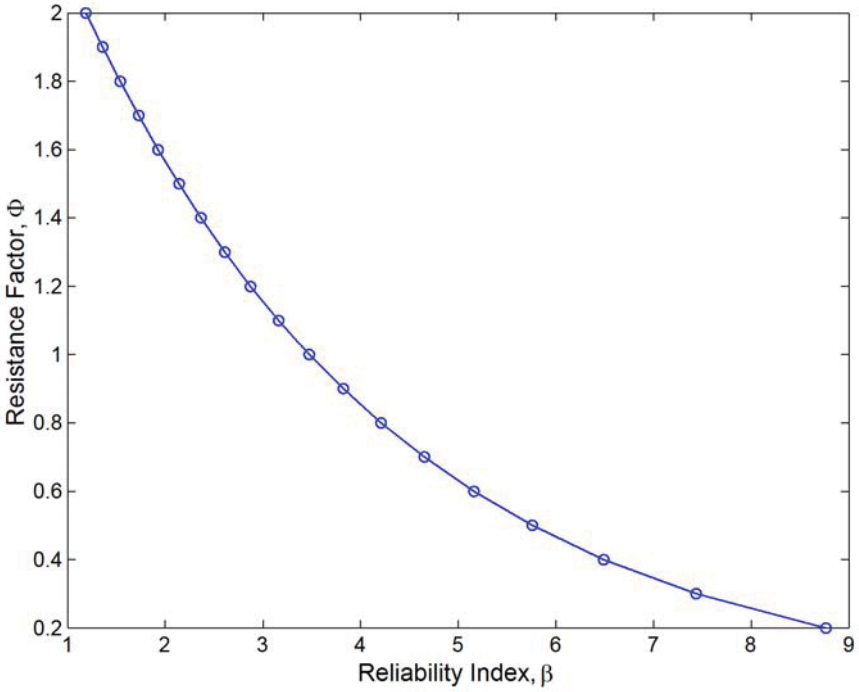


Figure A-23b Resistance Factor Calibration from
8 CAPWAP-EOD pile-cases in California

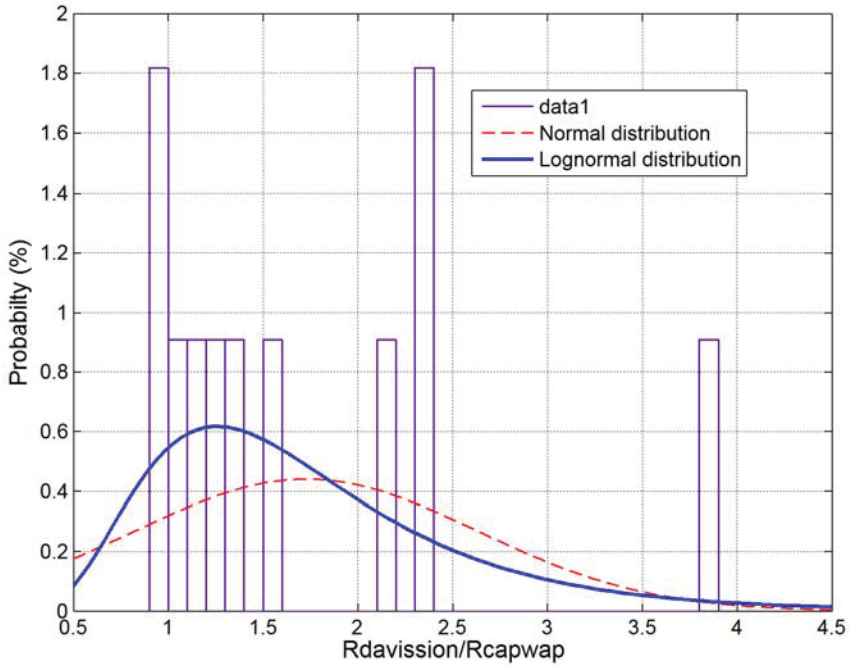


Figure A-24a Frequency Distribution for 11 CAPWAP-EOD Cases in Massachusetts

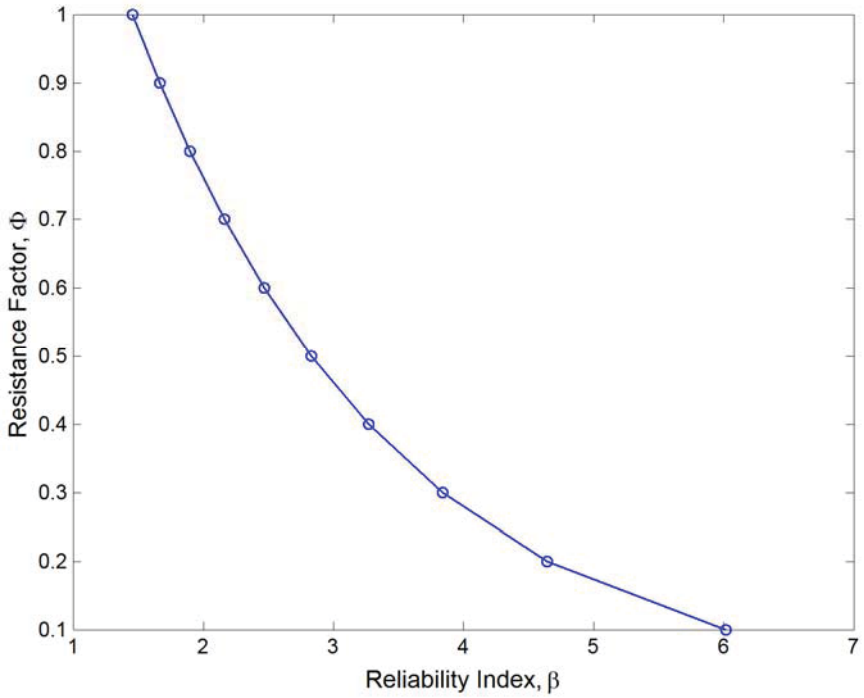


Figure A-24b Resistance Factor Calibration from
11 CAPWAP-EOD pile-cases in Massachusetts

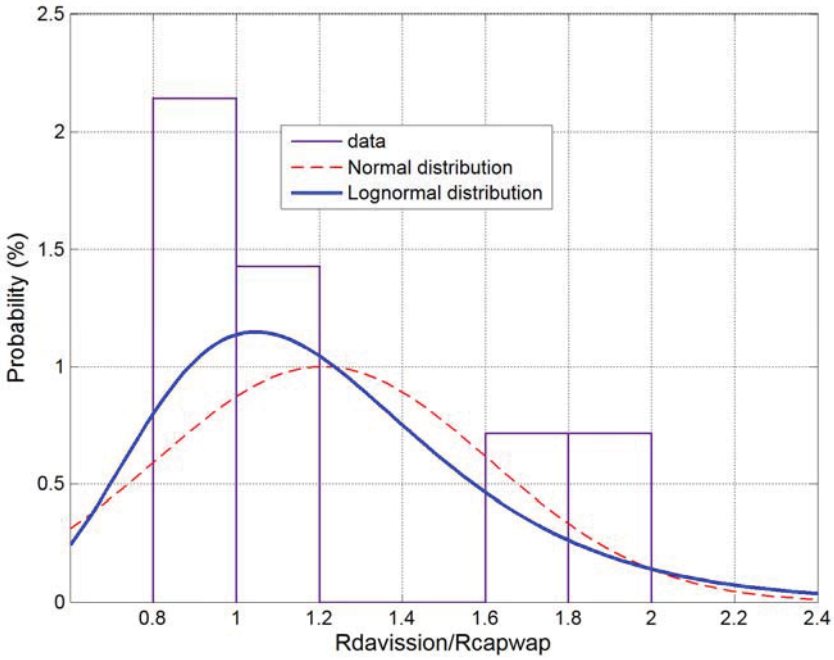


Figure A-25a Frequency Distribution for 7 CAPWAP-EOD Cases in Ontario

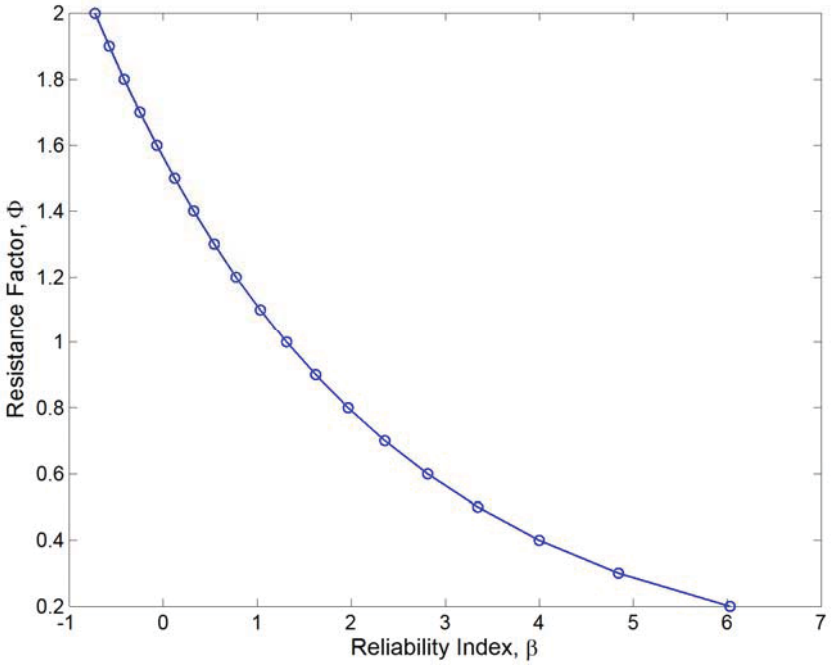


Figure A-25b Resistance Factor Calibration from
7 CAPWAP-EOD pile-cases in Ontario

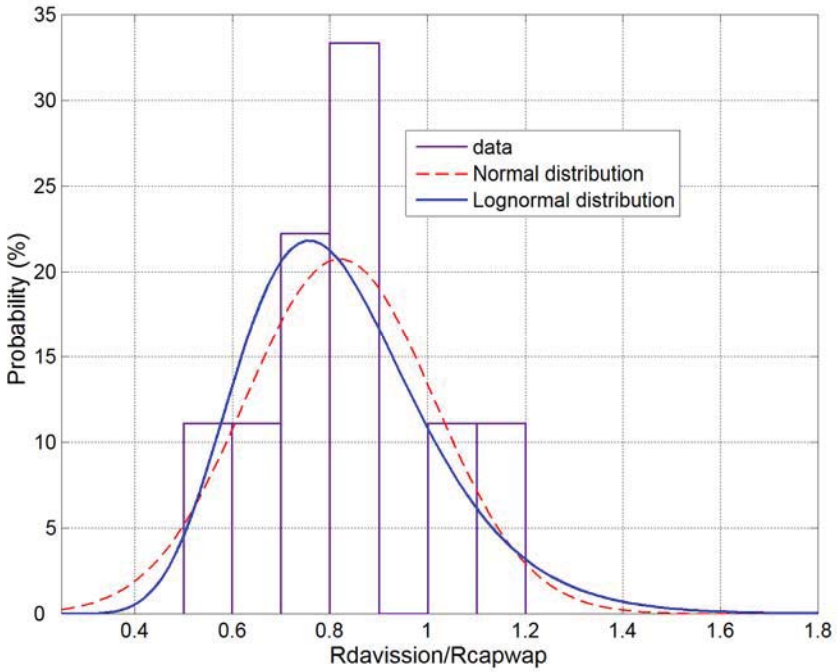


Figure A-26a Frequency Distribution for 9 CAPWAP-EOD Cases in Pittsburgh, PA

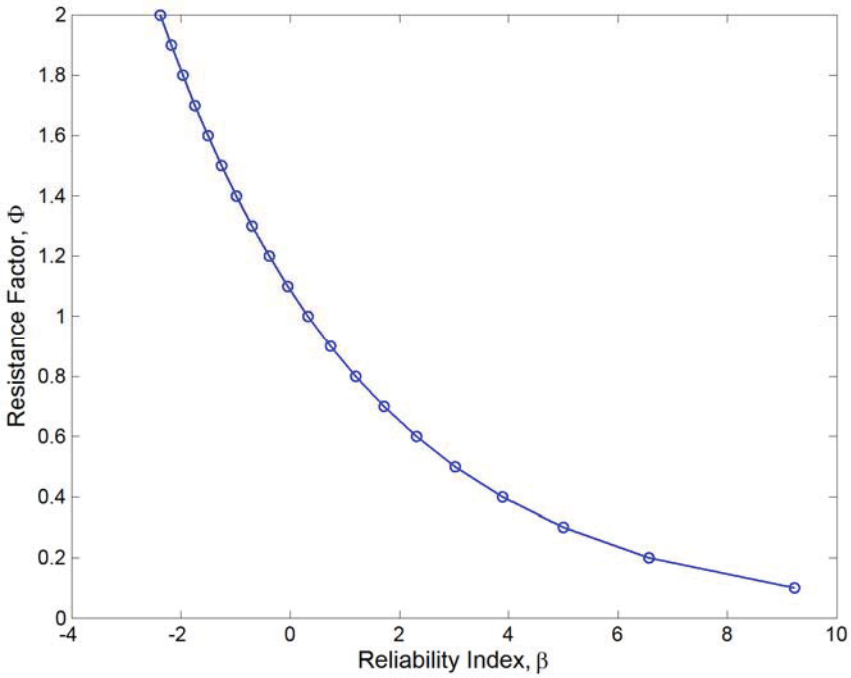


Figure A-26b Resistance Factor Calibration from
8 CAPWAP-EOD pile-cases in Pittsburgh, PA

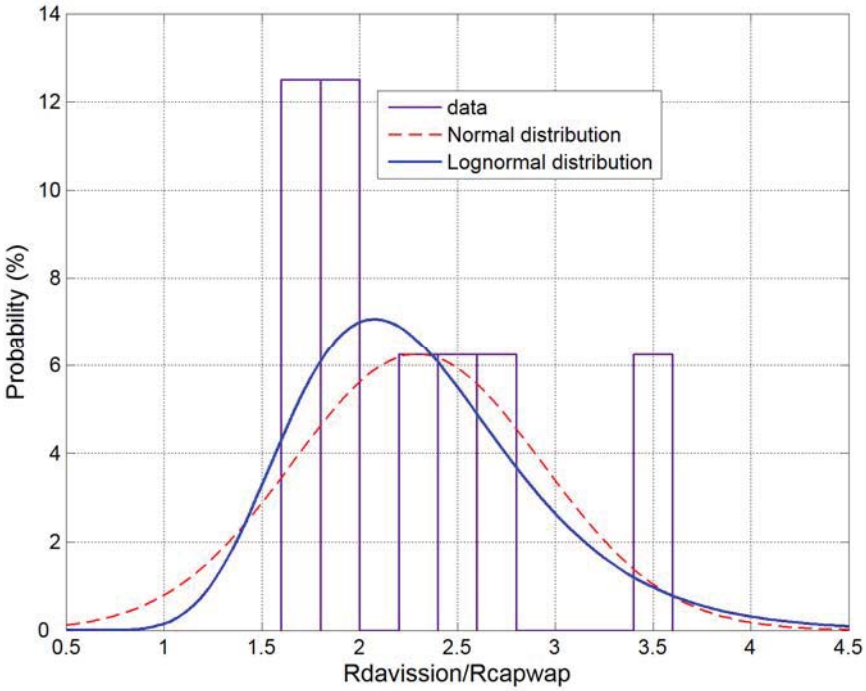


Figure A-27a Frequency Distribution for 8 CAPWAP-EOD Cases in Wisconsin

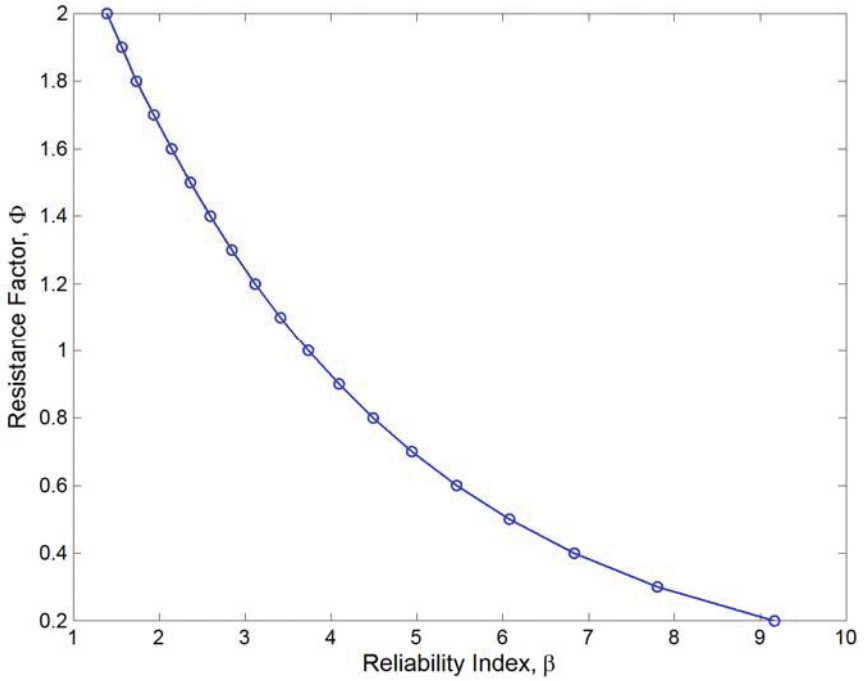


Figure A-27b Resistance Factor Calibration from
8 CAPWAP-EOD pile-cases in Wisconsin

APPENDIX B
Calibration Resistance Factor by Using FORM for Driven Pile using Static Analysis

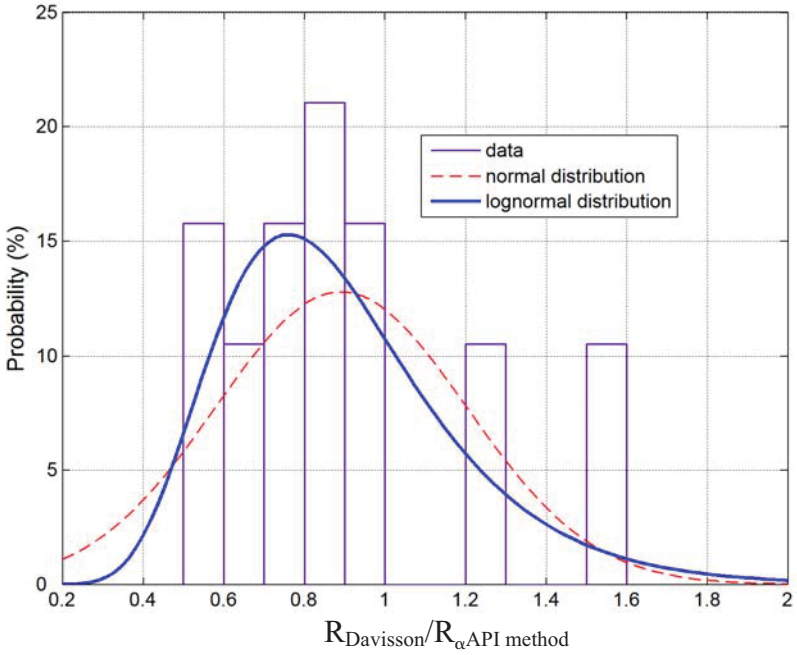


Figure B-1a Frequency Distribution for All 19 Concrete Pile Cases in Clay by Using αAPI Method

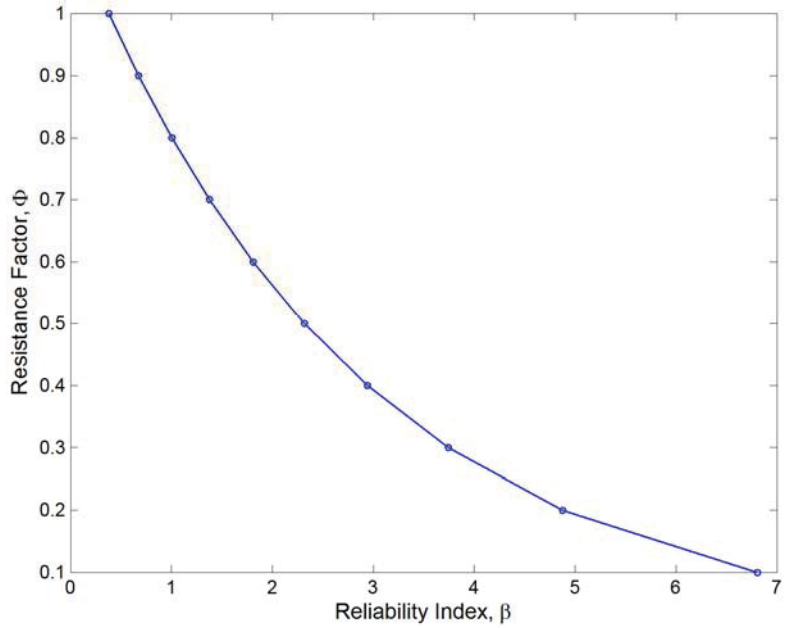


Figure B-1b Resistance Factor Calibrations from All 19 Concrete Pile Cases in Clay by Using αAPI Method

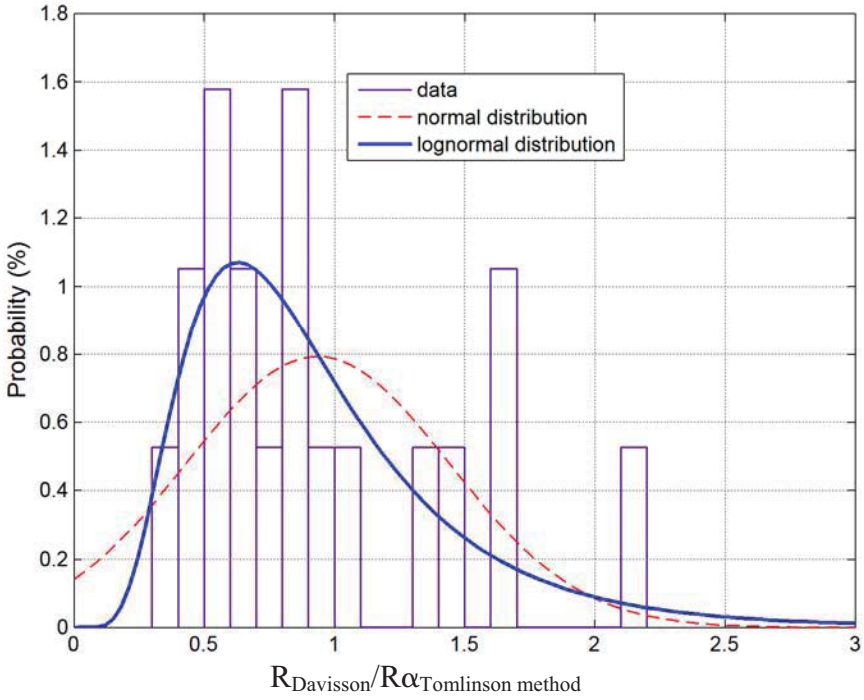


Figure B-2a Frequency Distribution for All 19 Concrete Pile Cases in Clay by Using αTomlinson Method

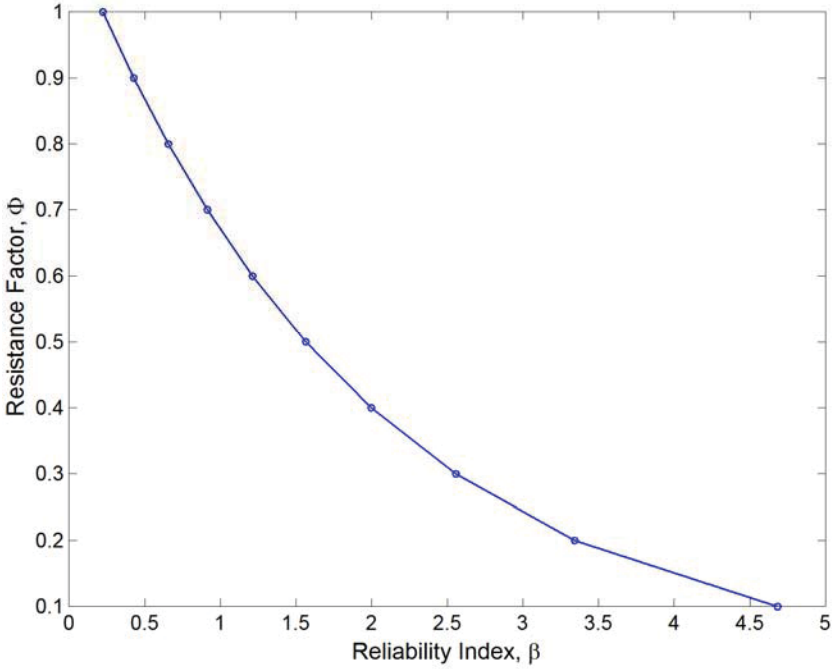


Figure B-2b Resistance Factor Calibration by FORM from All 19 Concrete Pile Cases in Clay by Using αTomlinson Method

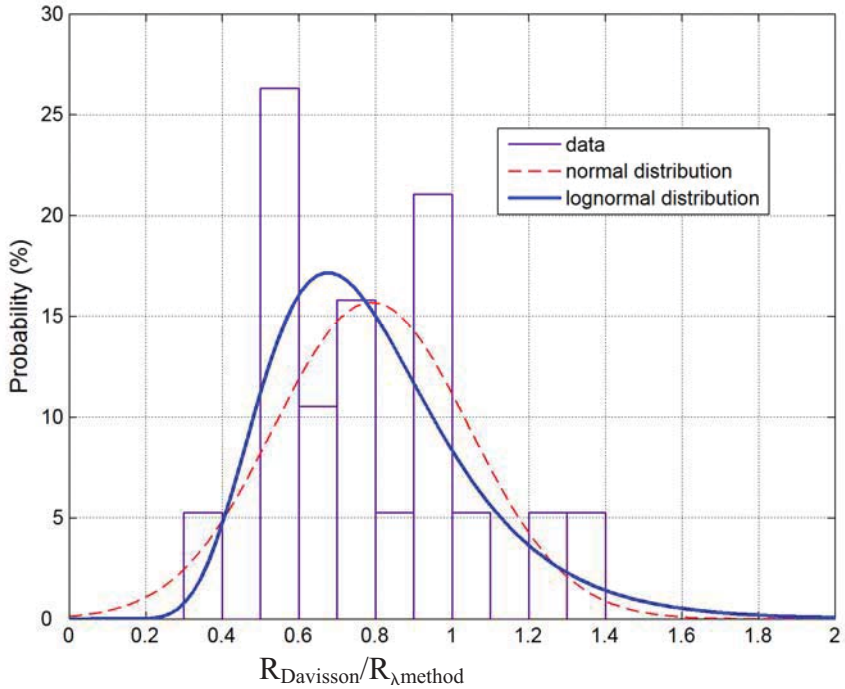


Figure B-3a Frequency Distribution for All 19 Concrete Pile Cases in Clay by Using λ Method

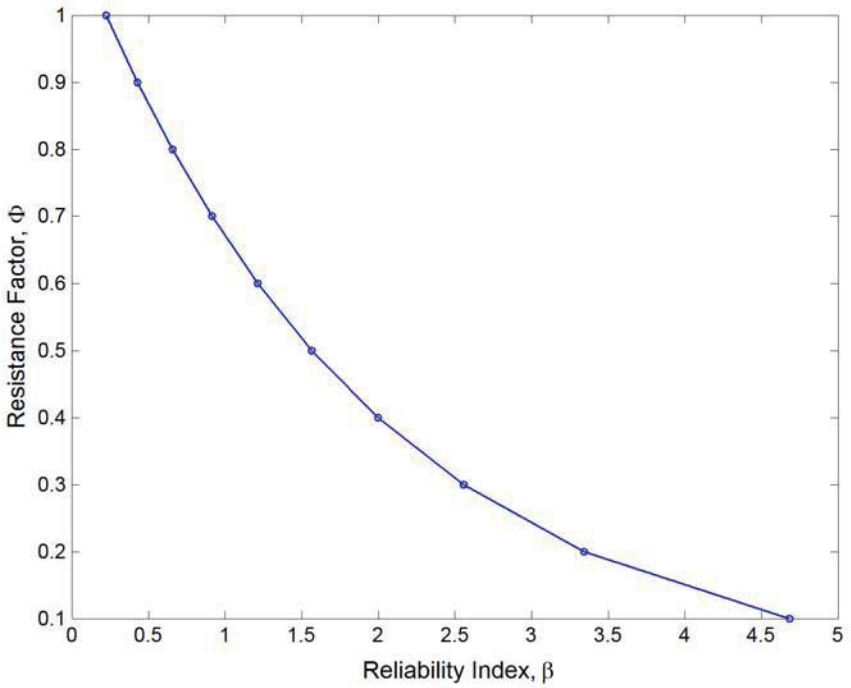


Figure B-3b Resistance Factor Calibration from All 19 Concrete Pile Cases in Clay by Using λ Method

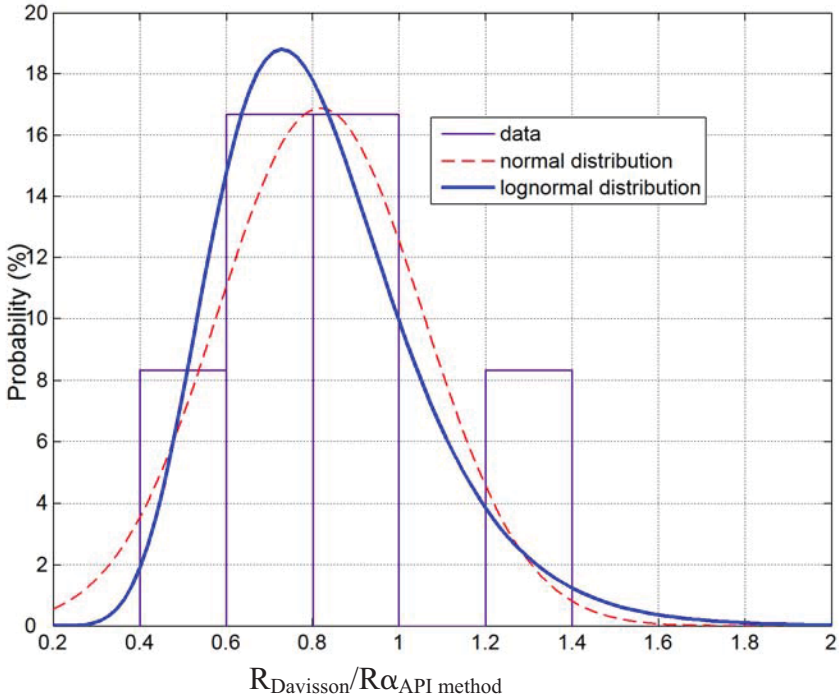


Figure B-4a Frequency Distribution for 12
Concrete Pile Cases in Clay in Louisiana by Using αAPI method

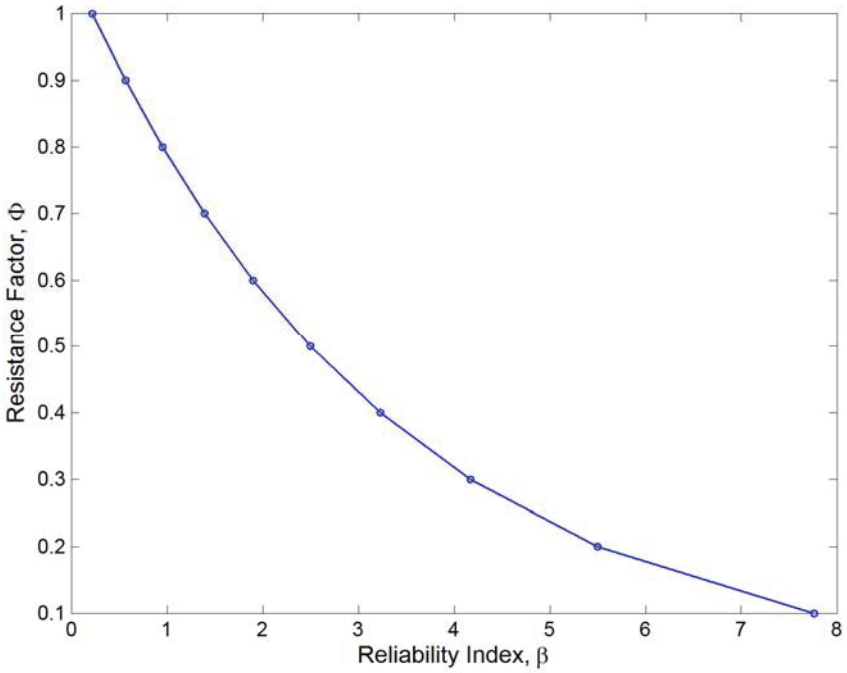


Figure B-4b Resistance Factor Calibration from
12 Concrete Pile Cases in Clay in Louisiana by Using αAPI method

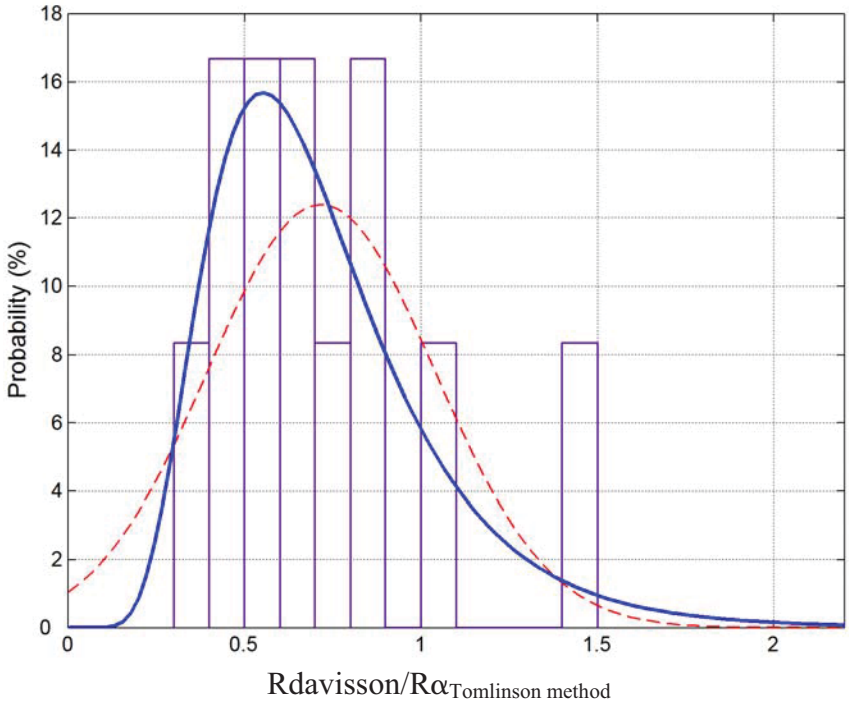


Figure B-5a Frequency Distribution for 12 Concrete Pile Cases in Clay in Louisiana by Using αTomlinson Method

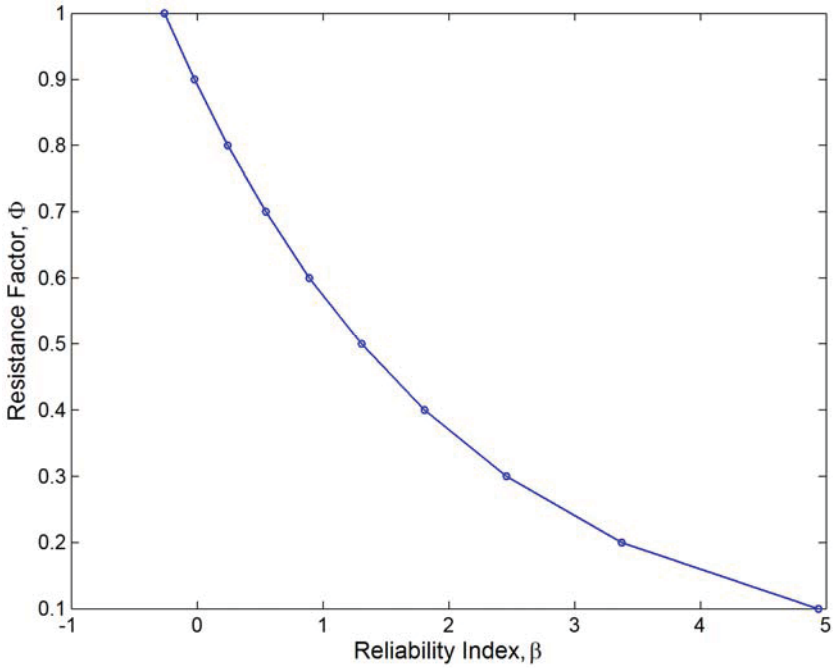


Figure B-5b Resistance Factor Calibration from 12 Concrete Pile Cases in Clay in Louisiana by Using αTomlinson Method

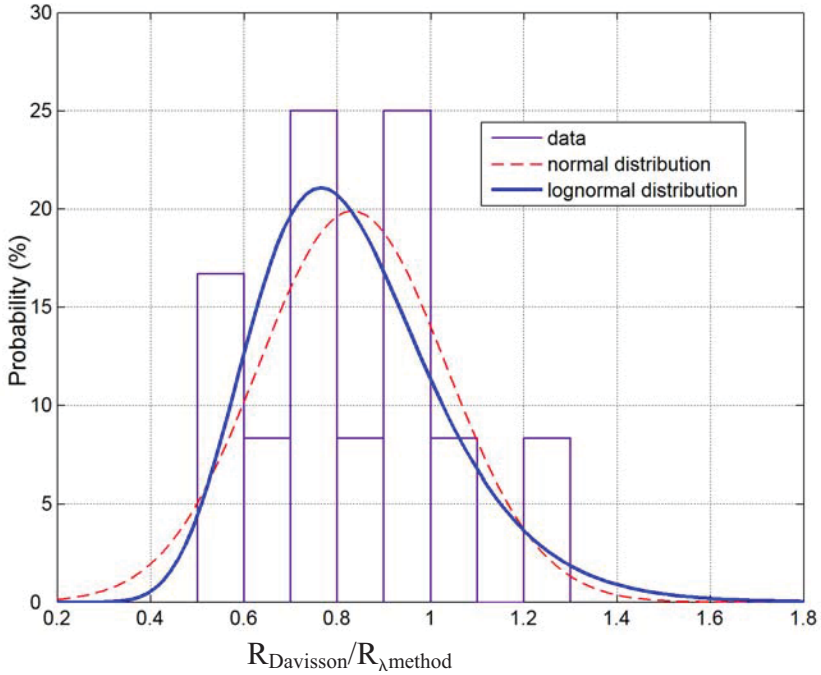


Figure B-6a Frequency Distribution for 12 Concrete Pile Cases in Clay in Louisiana by Using λ Method

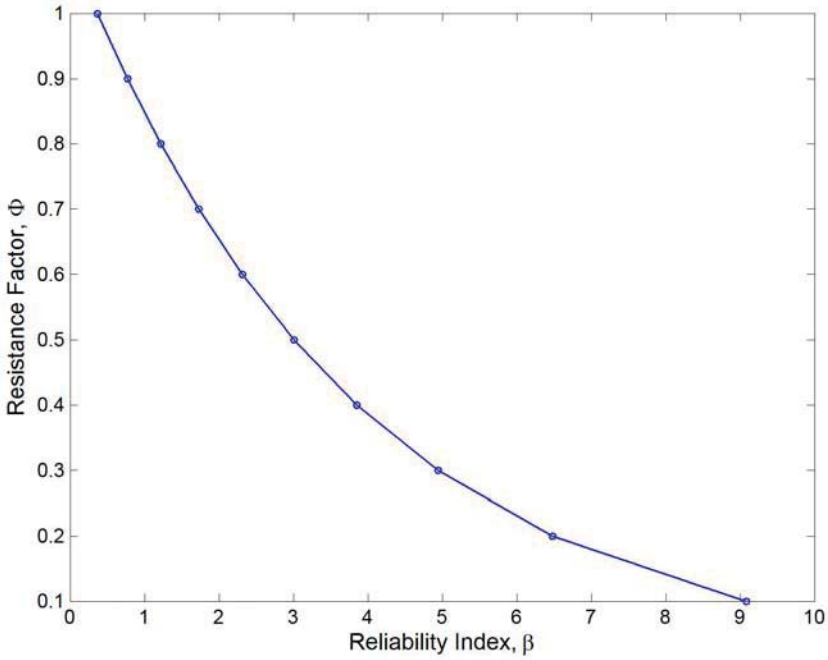


Figure B-6b Resistance Factor Calibration from 12 Concrete Pile Cases in Clay in Louisiana by Using λ Method

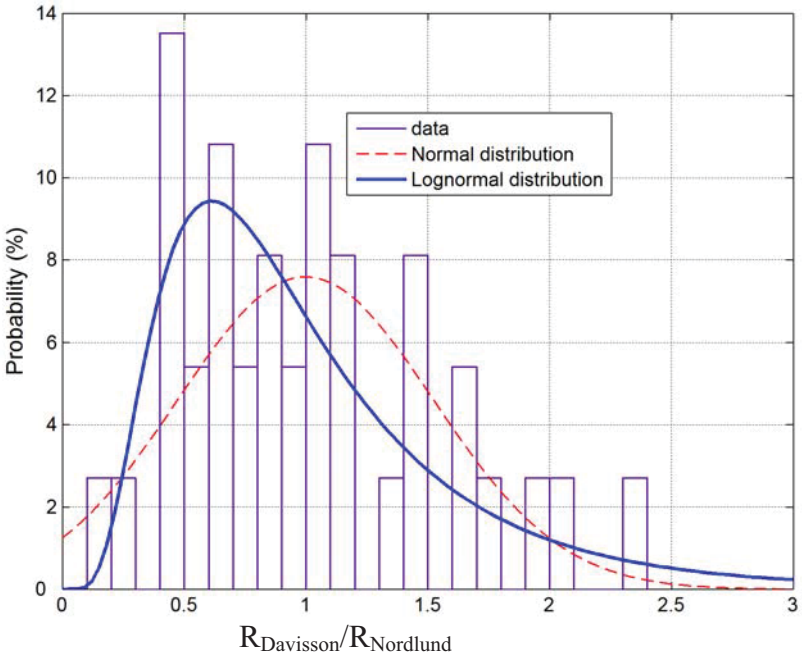


Figure B-7a Frequency Distribution for All 37 Concrete Pile Cases in Sand by Using Nordlund Method

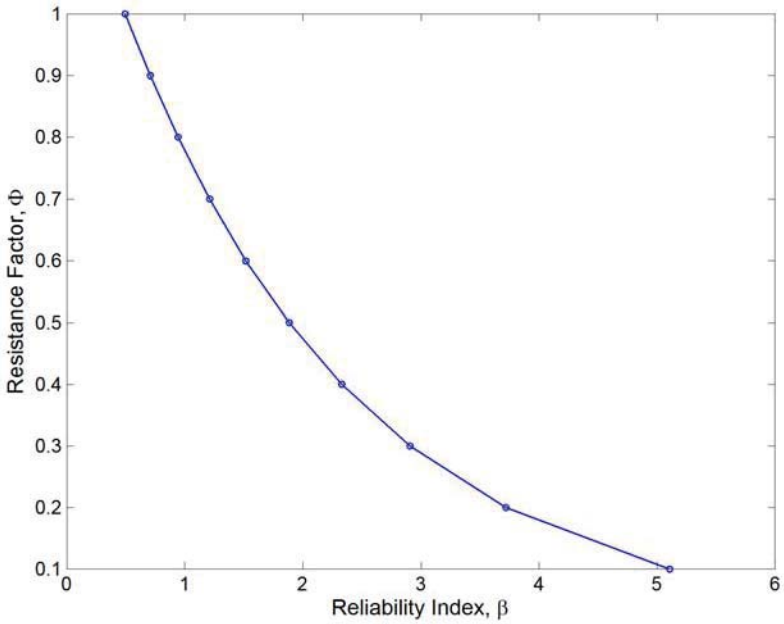


Figure B-7b Resistance Factor Calibration from all 37 Concrete Pile Cases in Sand by Using Nordlund Method

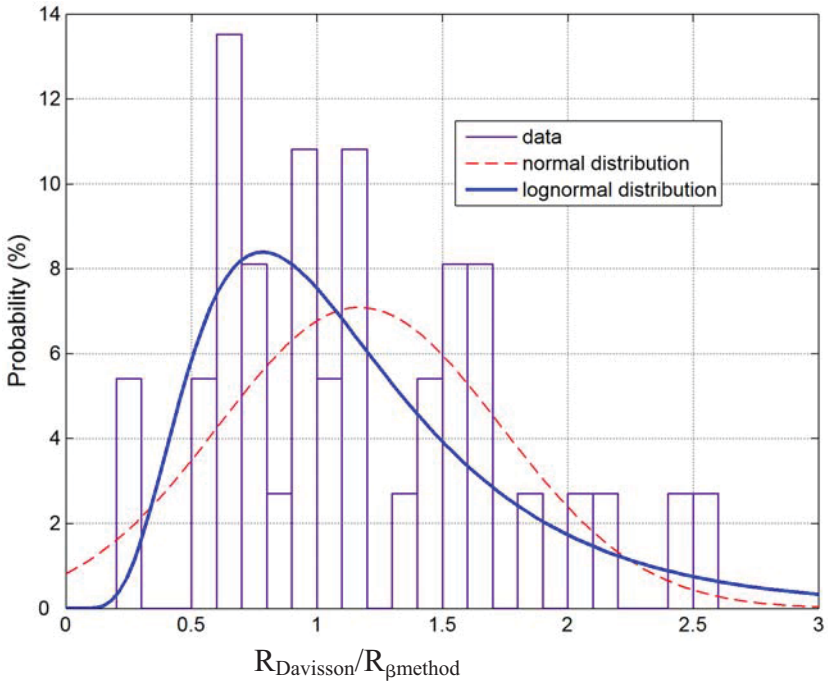


Figure B-8a Frequency Distribution for All 37 Concrete Pile Cases in Sand by Using β Method

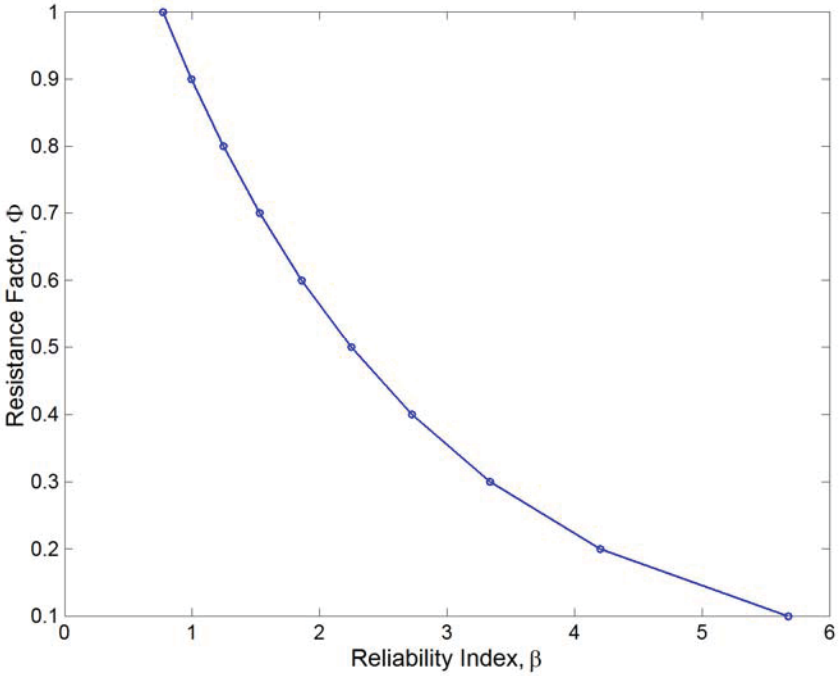


Figure B-8b Resistance Factor Calibration from all 37 Concrete Pile Cases in Sand by Using β Method

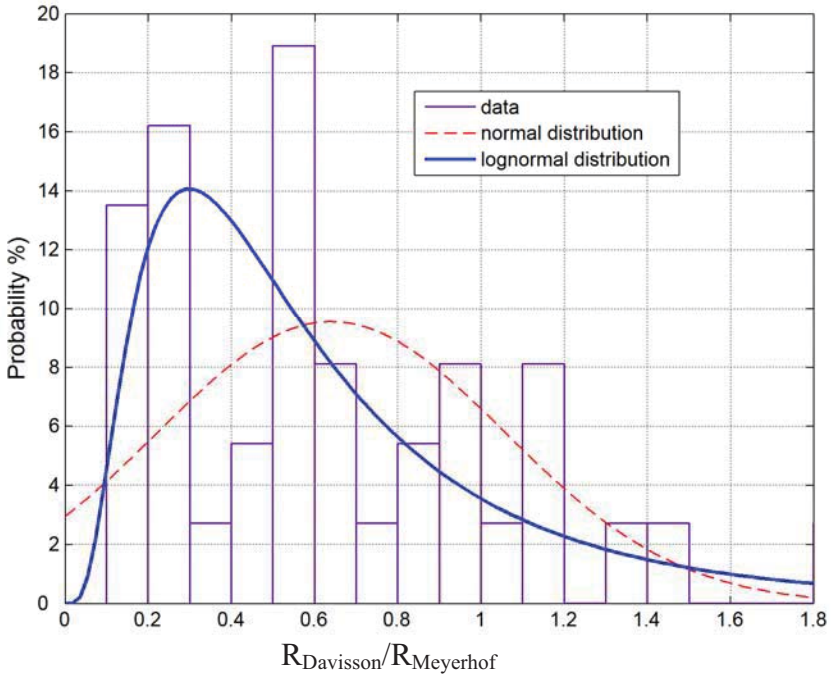


Figure B-9a Frequency Distribution for All 37 Concrete Pile Cases in Sand by Using Meyerhof

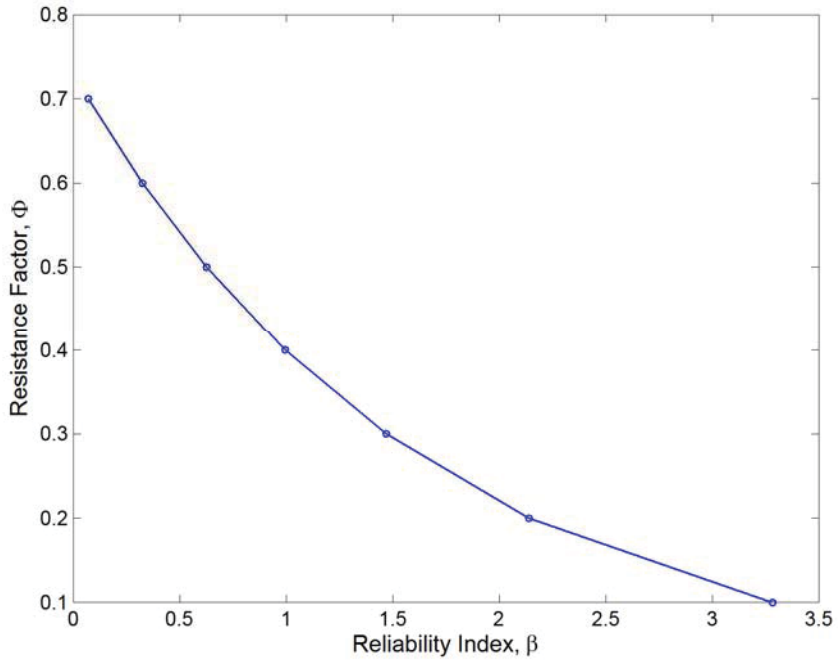


Figure B-9b Resistance Factor Calibration from All 37 Concrete Piles Cases in Sand by Using Meyerhof Method

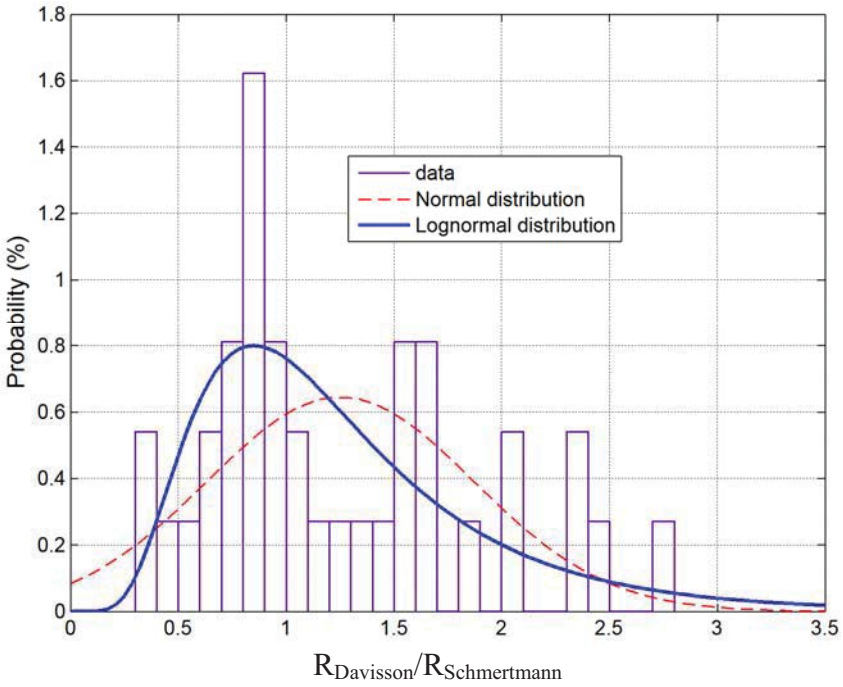


Figure B-10a Frequency Distribution for All 37 Concrete Pile Cases in Sand by Using Schmertmann Method

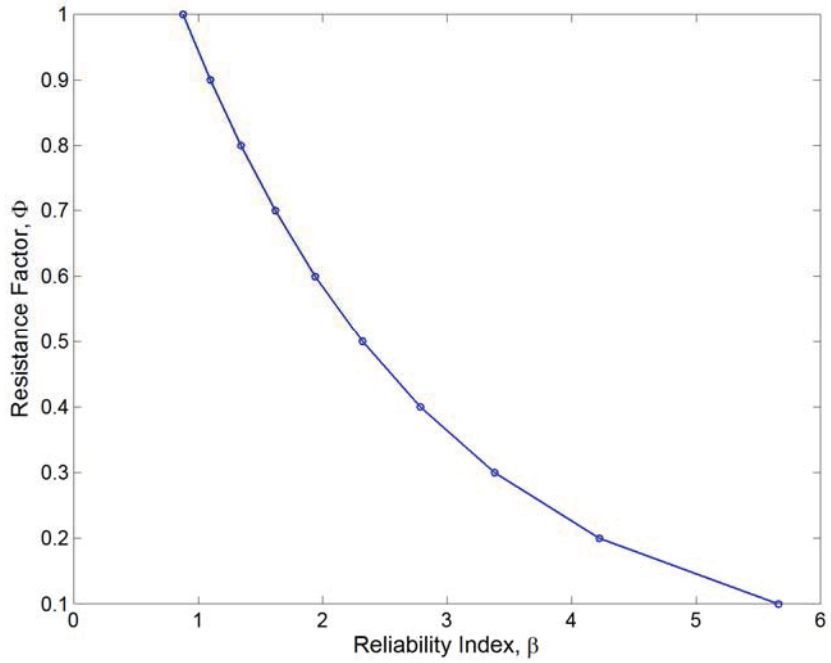


Figure B-10b Resistance Factor Calibration for All 37 Concrete Pile Cases Method in Sand by Using Schmertmann Method

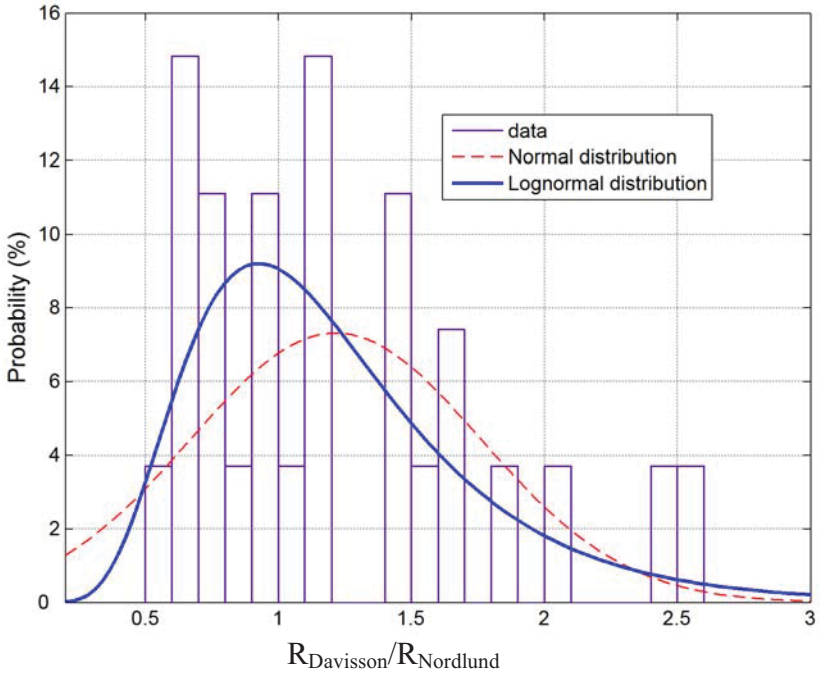


Figure B-11a Frequency Distribution for 27 Concrete Pile Cases in Sand in Florida by Using Nordlund Method

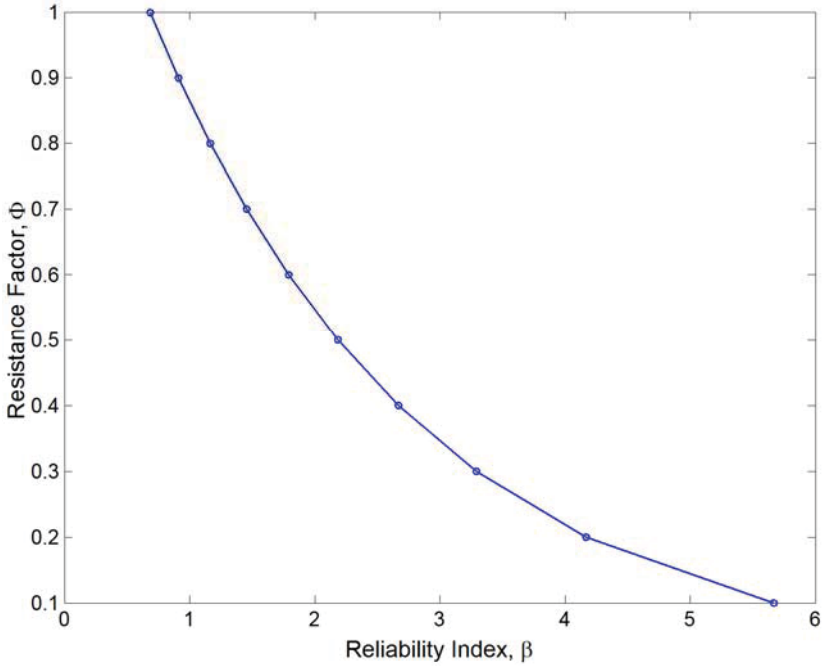


Figure B-11b Resistance Factor Calibration from 27 Concrete Pile Cases in Sand in Florida by Using Nordlund Method

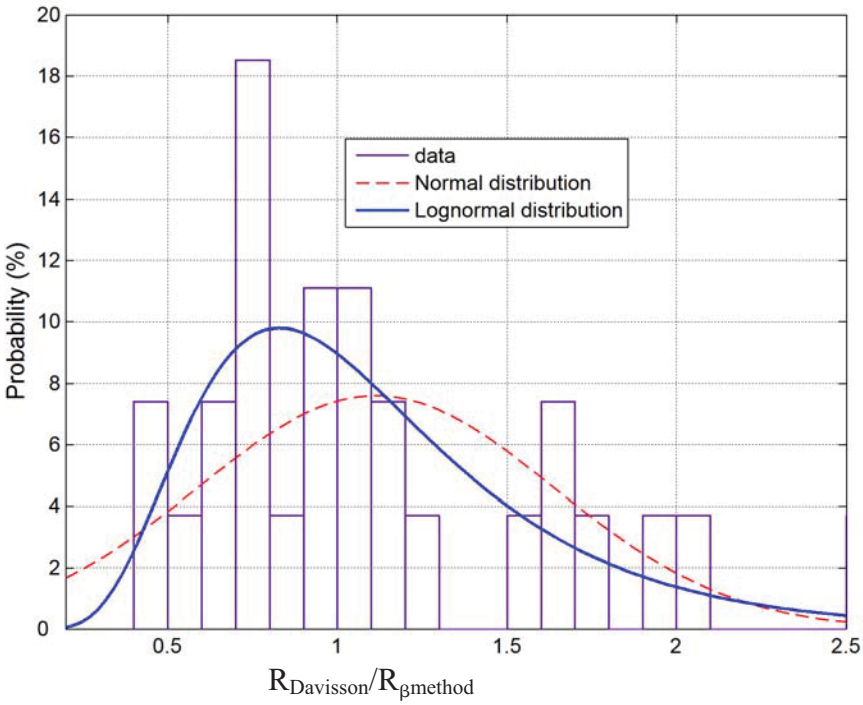


Figure B-12a Frequency Distribution for 27 Concrete pile Cases in Sand in Florida by Using β Method

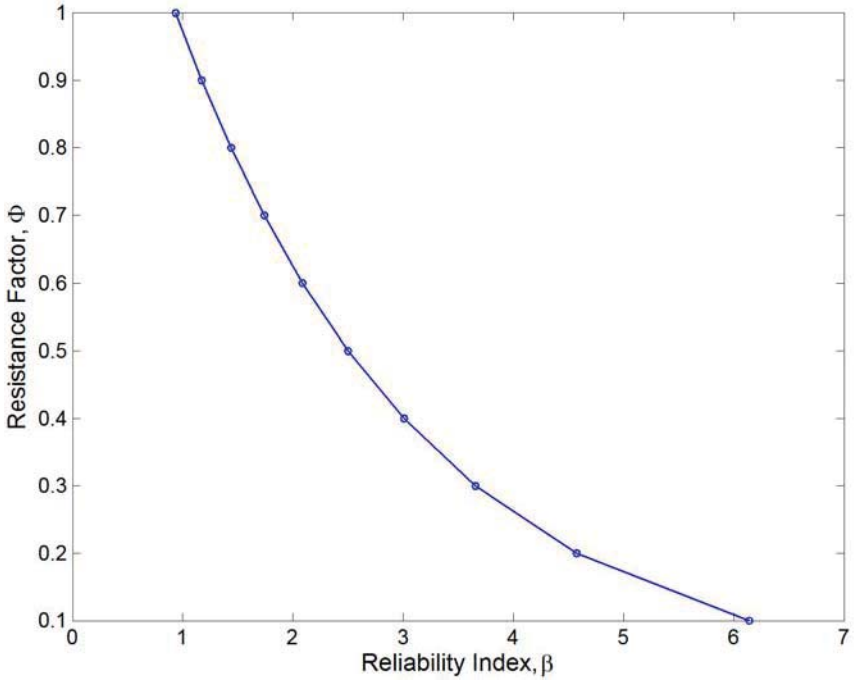


Figure B-12b Resistance Factor Calibration from 27 Concrete Pile Cases in Sand in Florida by Using β Method

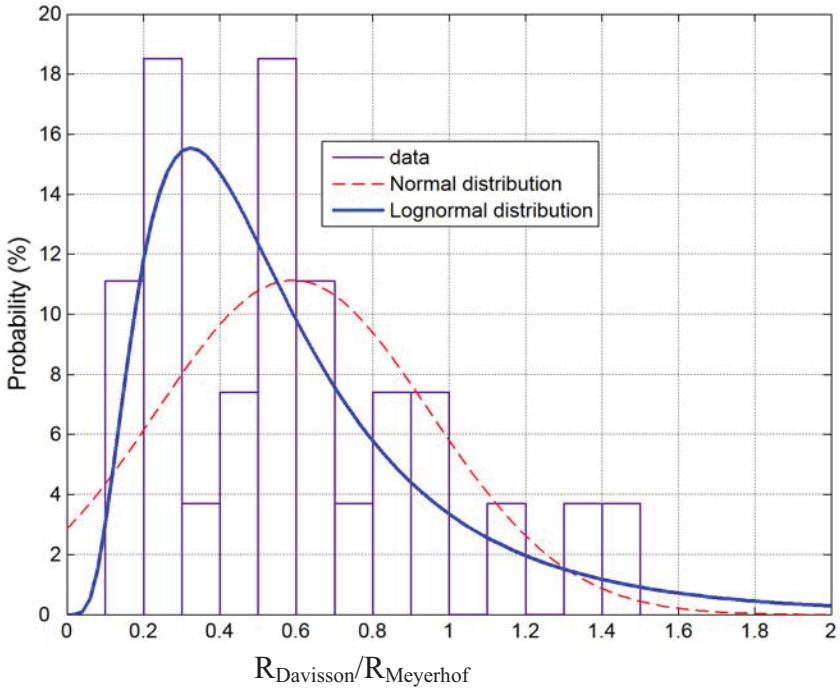


Figure B-13a Frequency Distribution for 27
Concrete Pile Cases in Sand in Florida by Using Meyerhof Method

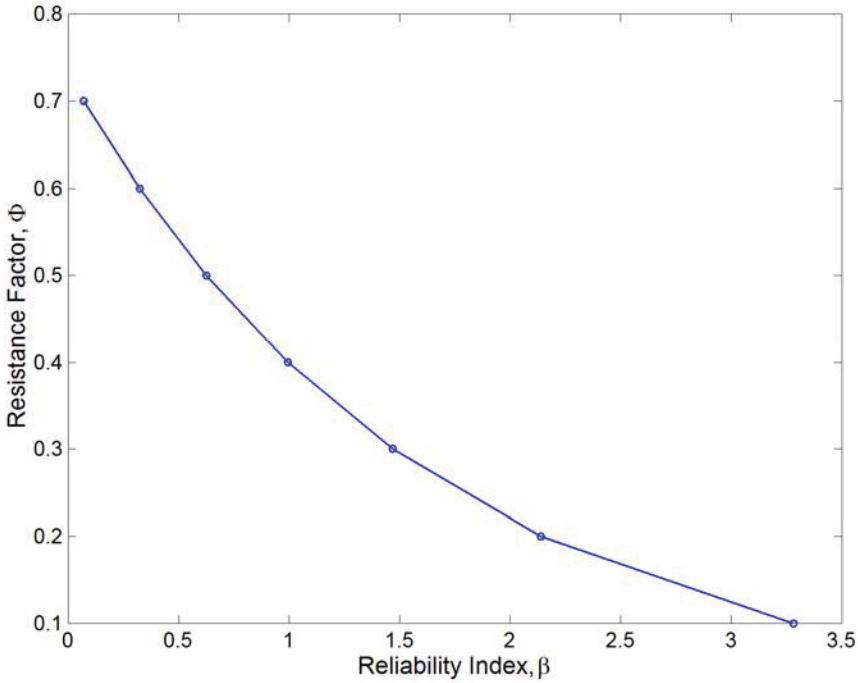


Figure B-13b Resistance Factor Calibration from
27 Concrete Pile Cases in Sand in Florida by Using Meyerhof Method

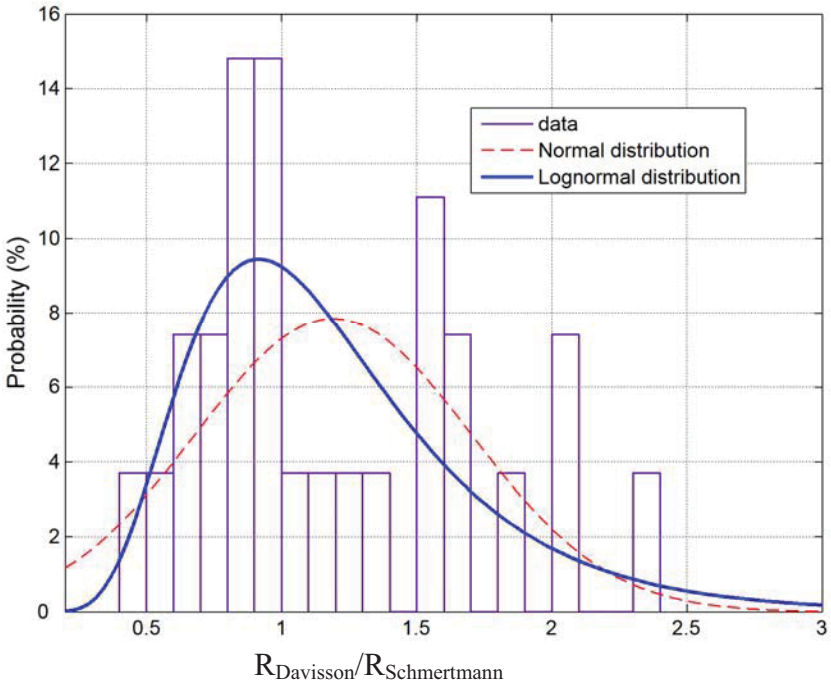


Figure B-14a Frequency Distribution for 27
Concrete Pile Cases in Sand in Florida by Using Schmertmann Method

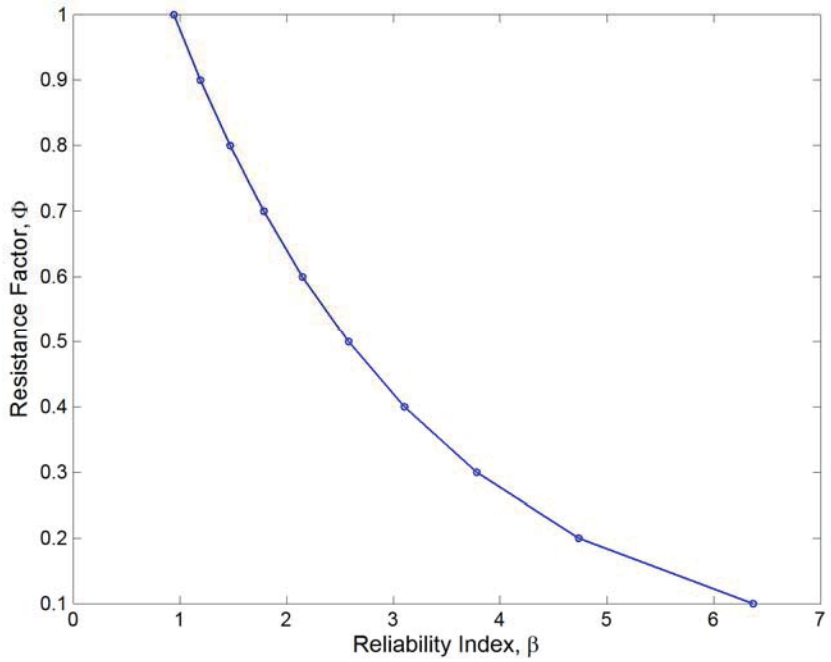


Figure B-14b Resistance Factor Calibration from
27 Concrete Pile Cases in Sand in Florida by Using Schmertmann Method

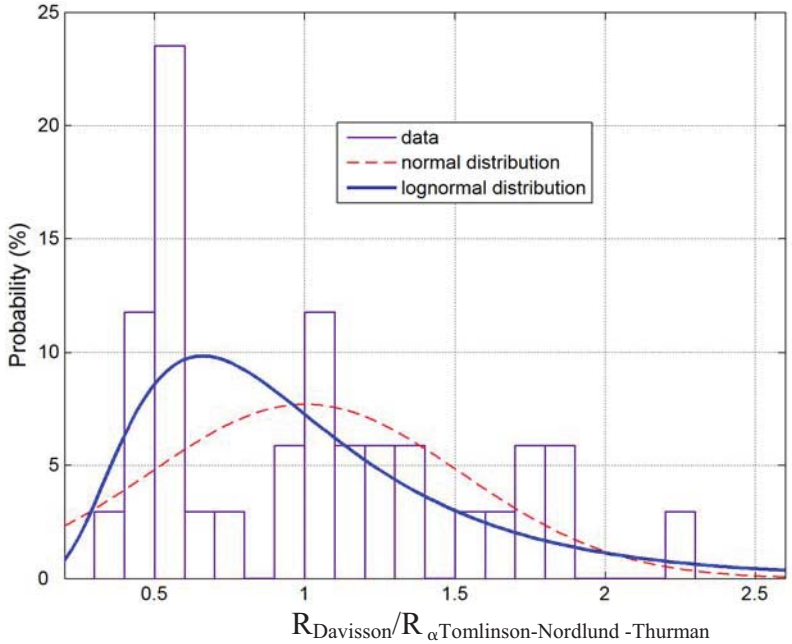


Figure B-15a Frequency Distribution for All 34 Concrete Pile Cases in Mixed Soil by Using αTomlinson-Nordlund –Thurman Method

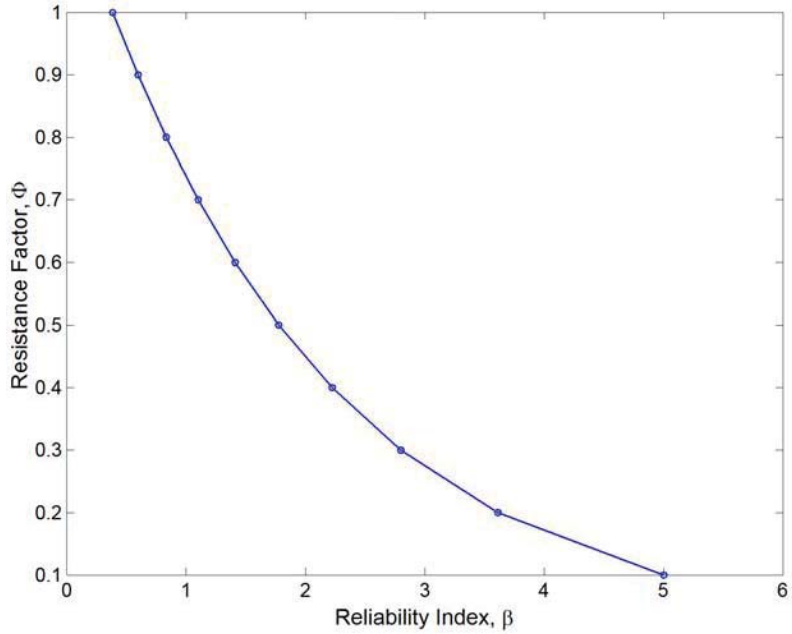


Figure B-15b Resistance Factor Calibration from All 34 Concrete Pile Cases in Mixed Soil by Using αTomlinson-Nordlund –Thurman Method

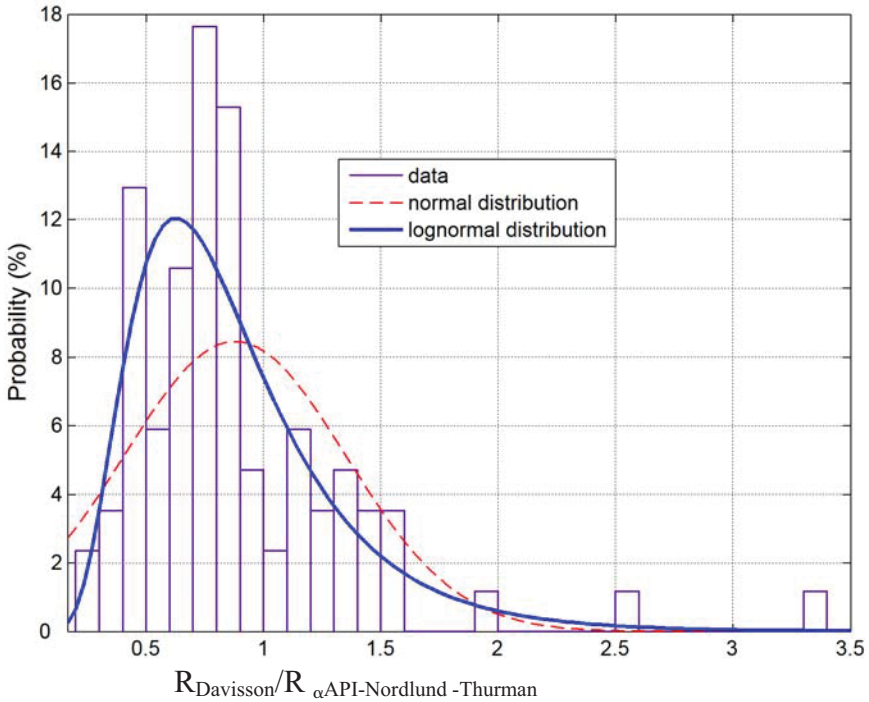


Figure B-16a Frequency Distribution for all 85 Concrete Pile Cases in Mixed Soil by Using αAPI-Nordlund –Thurman Method

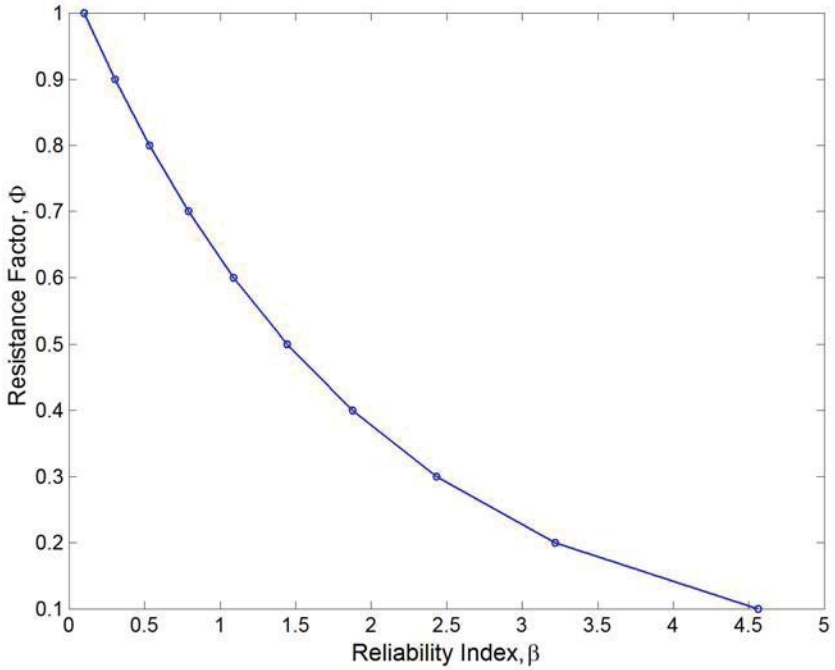


Figure B-16b Resistance Factor Calibration from All 85 Concrete Pile Cases in Mixed Soil by Using R αAPI-Nordlund –Thurman Method

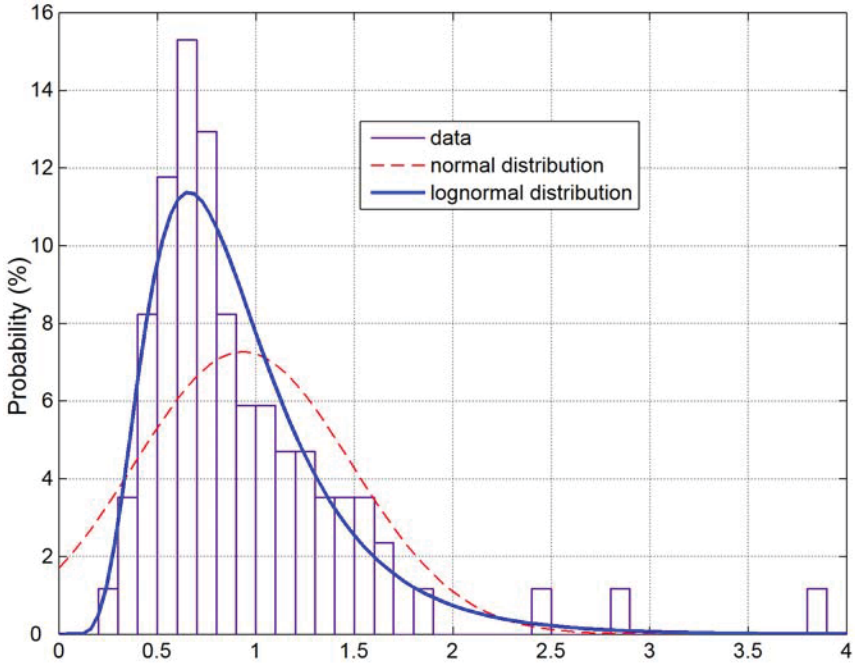


Figure B-17a Frequency Distribution for all 85 Concrete Pile Cases in Mixed Soil by Using β-Thurman Method

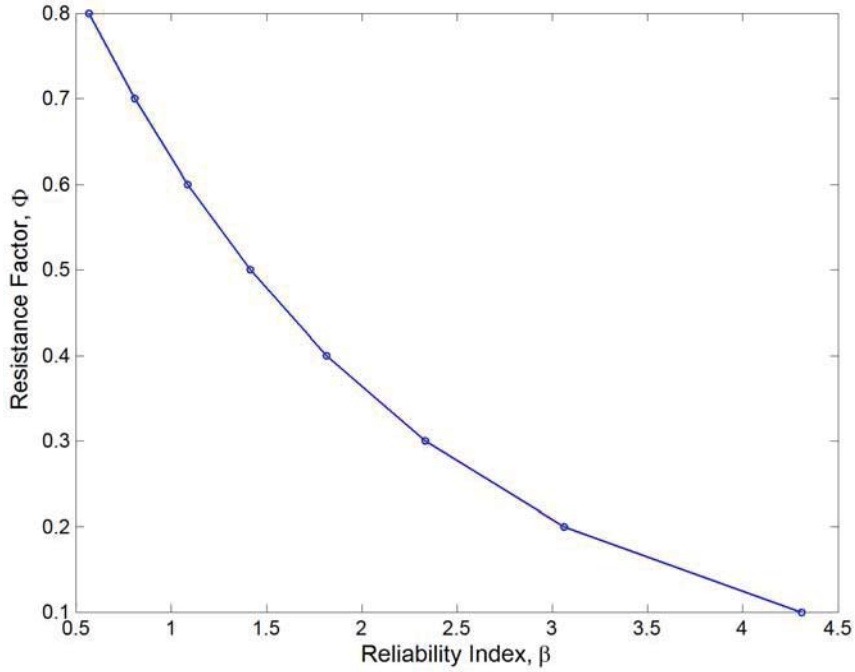


Figure B-17b Resistance Factor Calibration from All 85 Concrete Pile Cases in Mixed Soil by Using β-Thurman Method

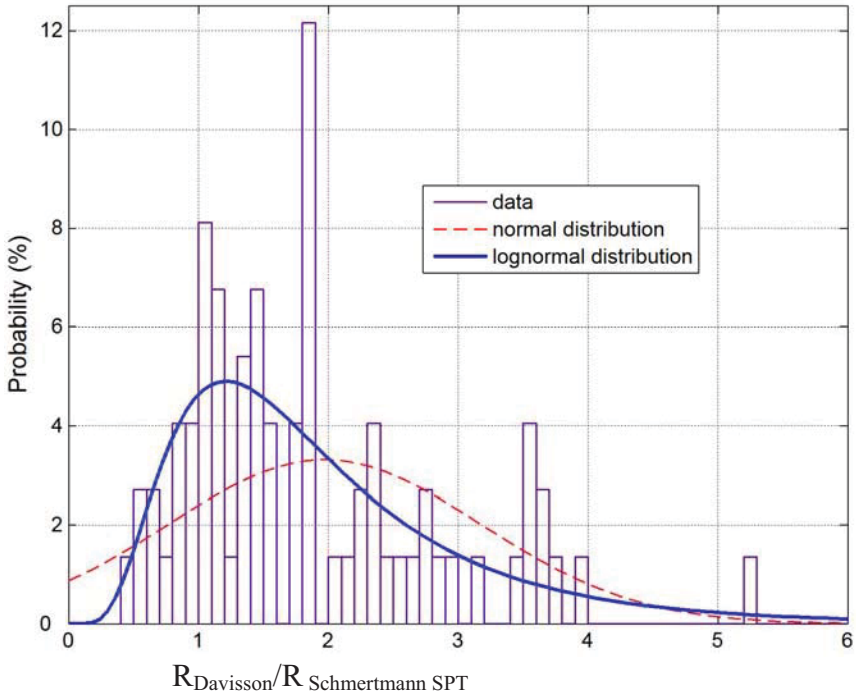


Figure B-18a Frequency Distribution for All 74 Concrete Pile Cases in Mixed Soil by Using Schmertmann SPT Method

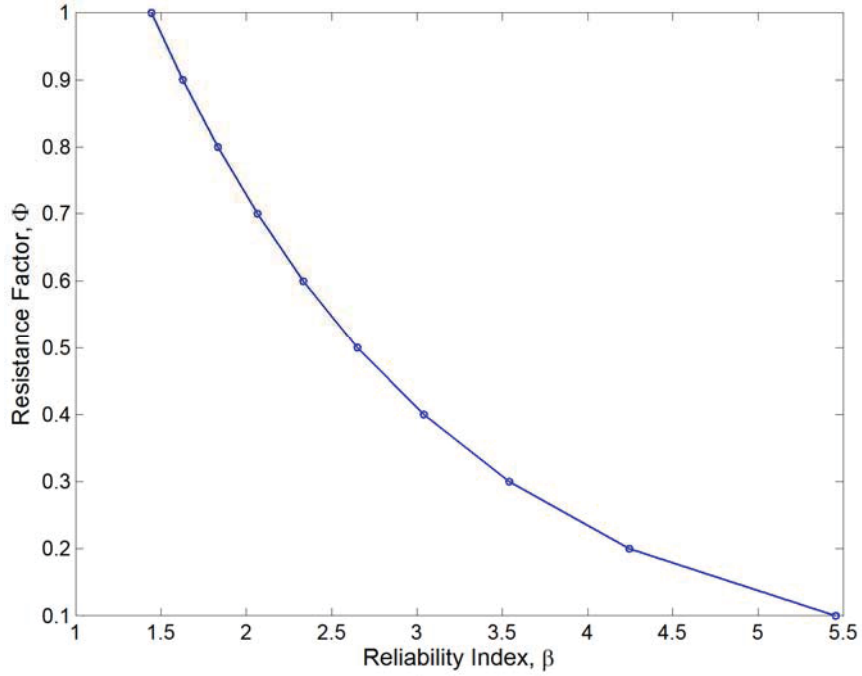


Figure B-18b Resistance Factor Calibration from all 74 Concrete Pile Cases in Mixed Soil by Using Schmertmann SPT Method

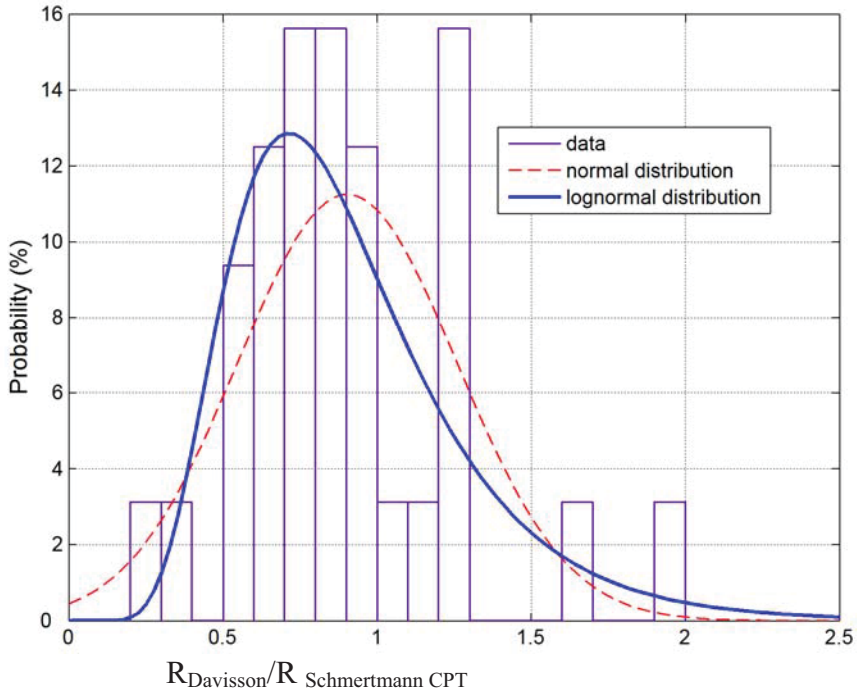


Figure B-19a Frequency Distribution for all 32 Concrete Pile Cases in Mixed Soil by Using Schmertmann CPT Method

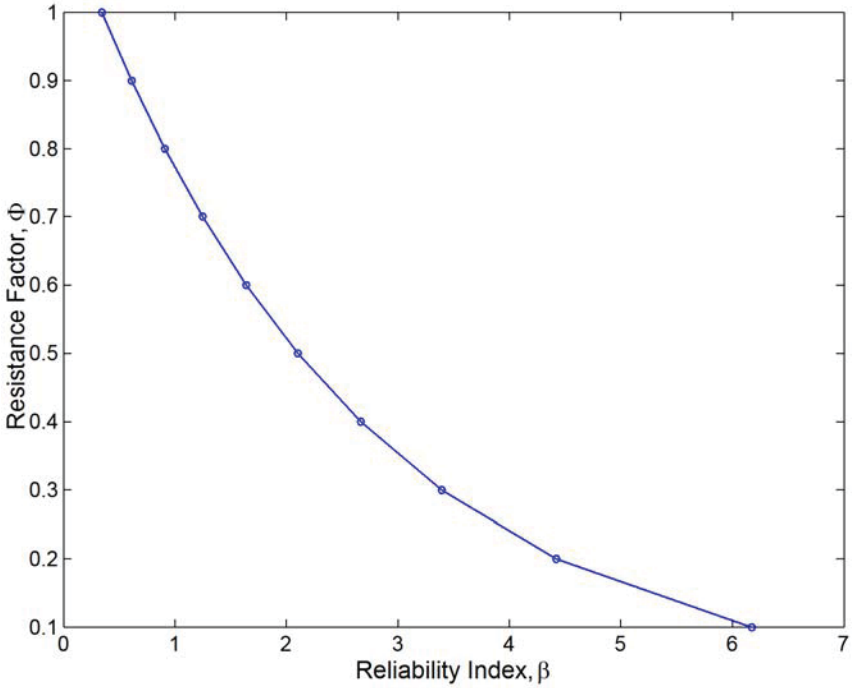


Figure B-19b Resistance Factor Calibration from all 32 Concrete Pile Cases in Mixed Soil by Using Schmertmann CPT Method

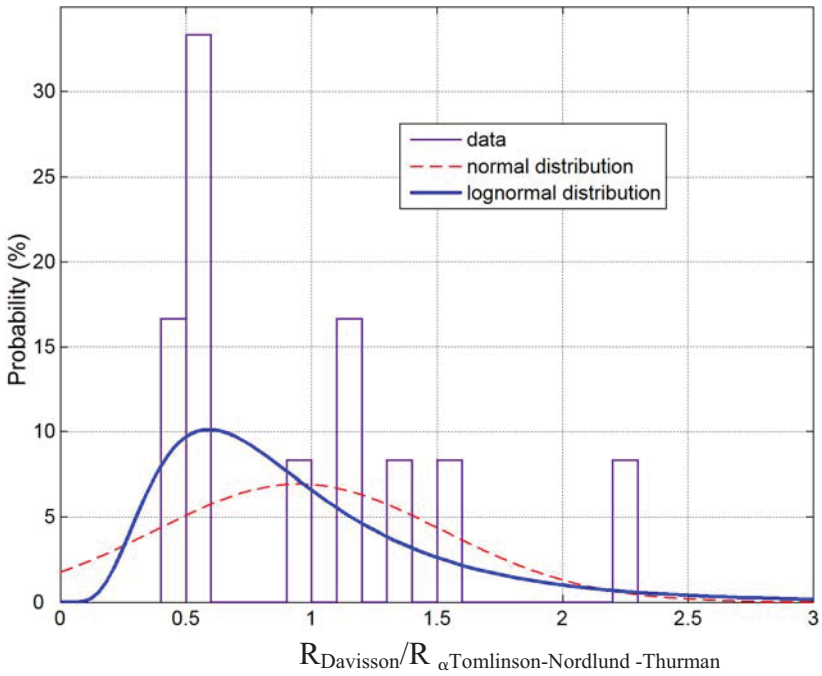


Figure B-20a Frequency Distribution for 12 Concrete Pile Cases in Mixed Soil in Florida by Using αTomlinson-Nordlund –Thurman Method

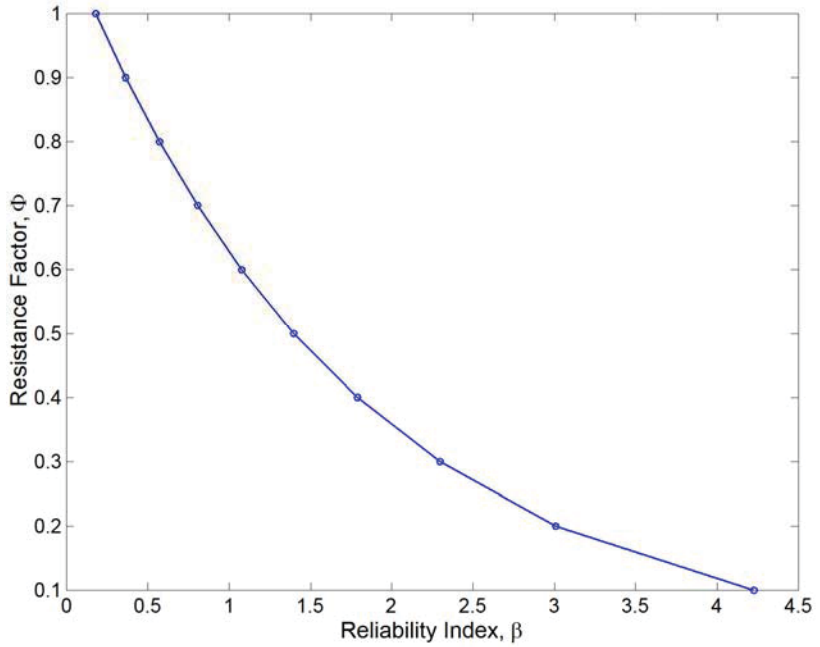


Figure B-20b Resistance Factor Calibration from 12 concrete pile cases in mixed soil in FL by Using αTomlinson-Nordlund –Thurman Method

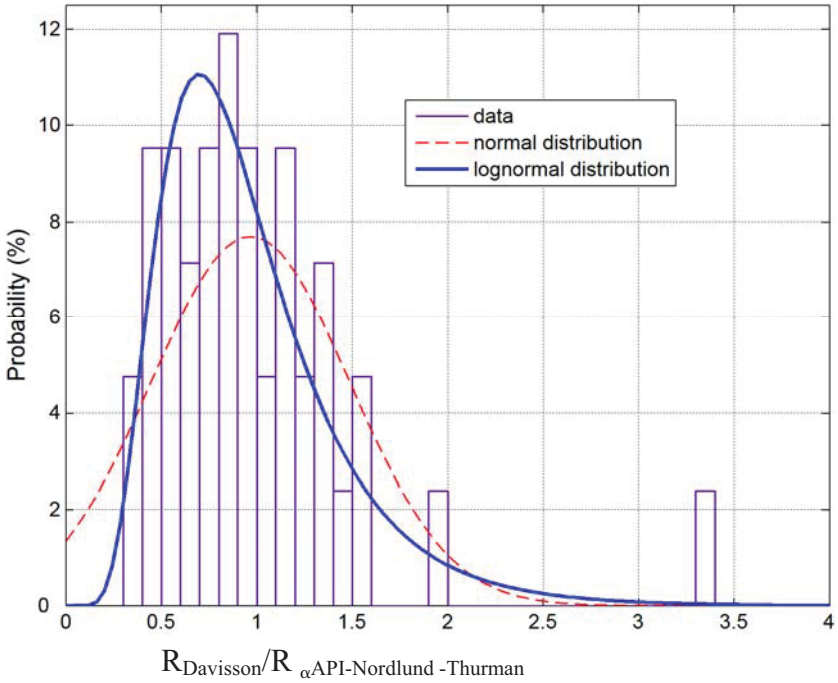


Figure B-21a Frequency Distribution for 42 Concrete Pile Cases in Mixed Soil in Florida by Using αAPI-Nordlund -Thurman

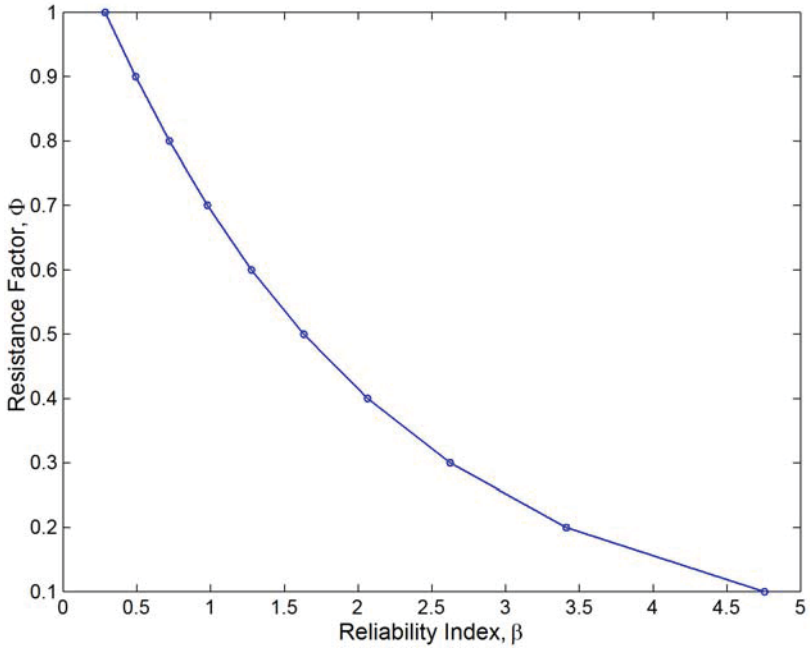


Figure B-21b Resistance Factor Calibration from 42 Concrete Pile Cases in Mixed Soil in Florida by Using αAPI-Nordlund -Thurman

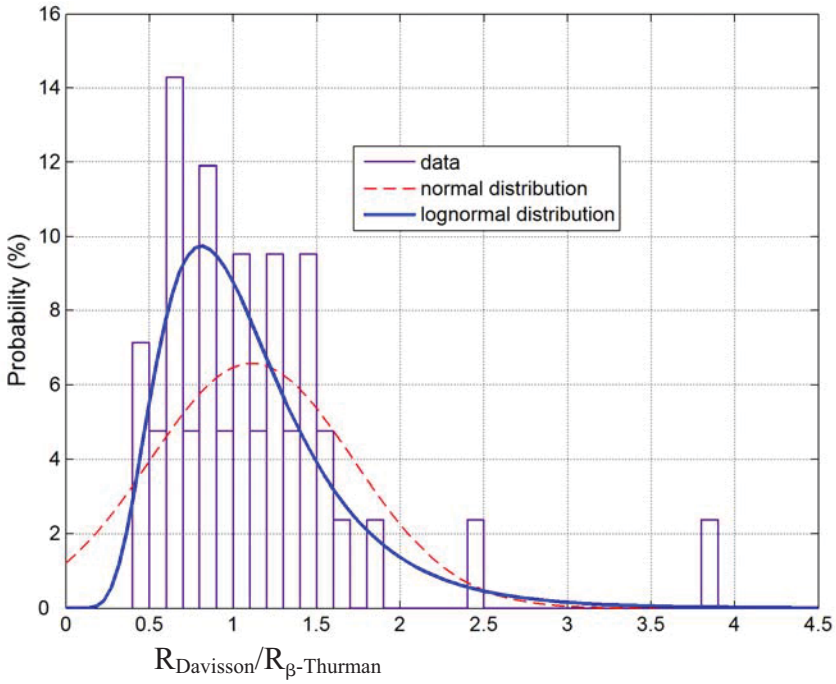


Figure B-22a Frequency Distribution for 42 Concrete Pile Cases in Mixed Soil in Florida by Using β-Thurman Method

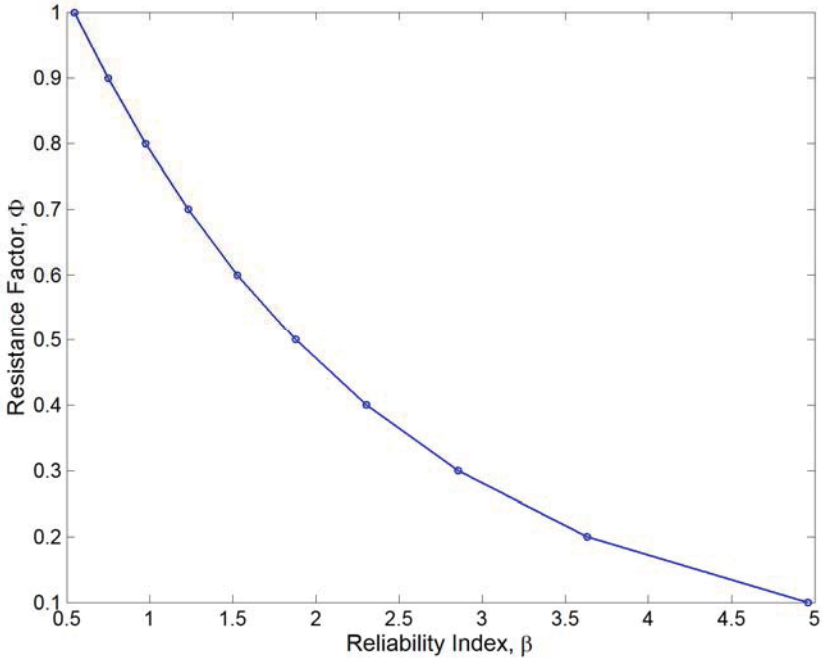


Figure B-22b Resistance Factor Calibration by FORM for 42 Concrete Pile Cases in Mixed Soil in Florida by Using β-Thurman Method

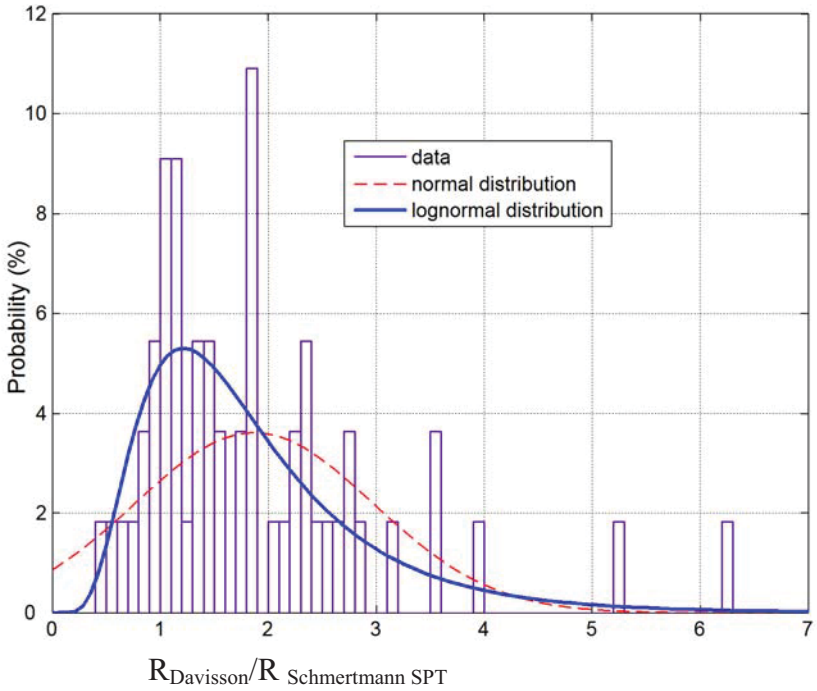


Figure B-23a Frequency Distribution for 55 Concrete Pile Cases in Mixed Soil in Florida by Using Schmertmann SPT Method

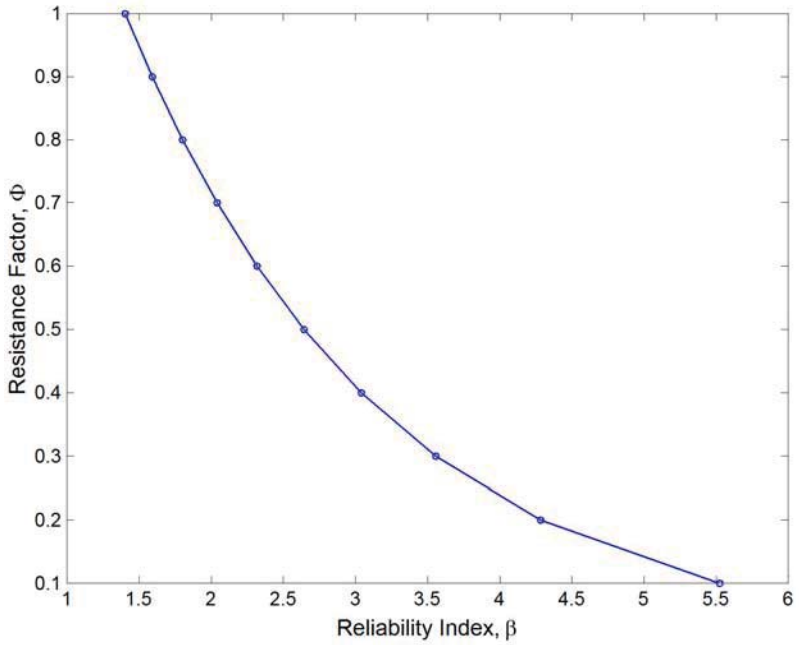


Figure B-23b Resistance Factor Calibration from 55 Concrete Pile Cases in Mixed Soil in Florida by Using Schmertmann SPT Method

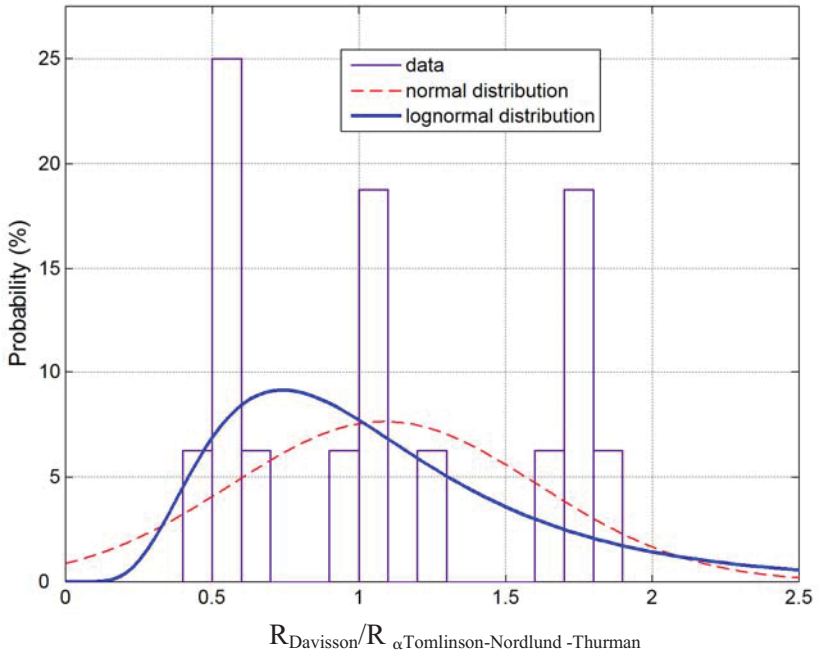


Figure B-24a Frequency Distribution for 16 Concrete Pile Cases in Mixed Soil in Louisiana by Using αTomlinson-Nordlund –Thurman Method

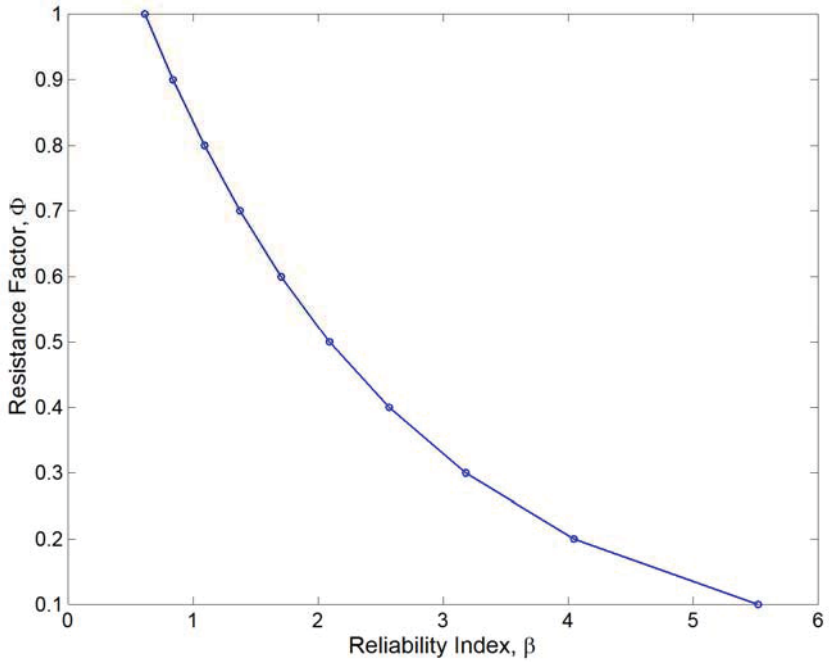


Figure B-24b Resistance Factor Calibration from 16 Concrete Pile Cases in Mixed soil in Louisiana by Using αTomlinson-Nordlund -Thurman Method

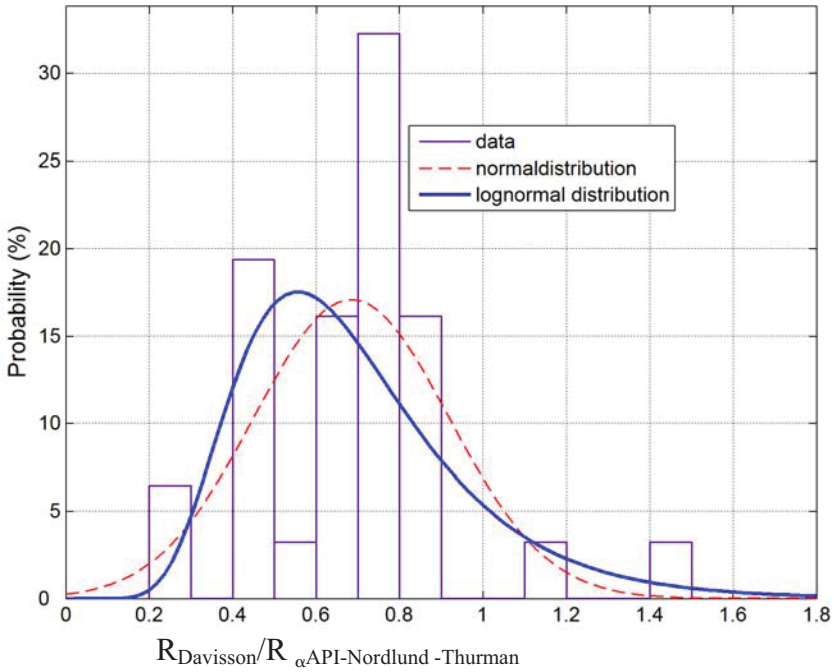


Figure B-25a Frequency Distribution for 31 Concrete Pile Cases in Mixed Soil in Louisiana by Using αAPI-Nordlund –Thurman Method

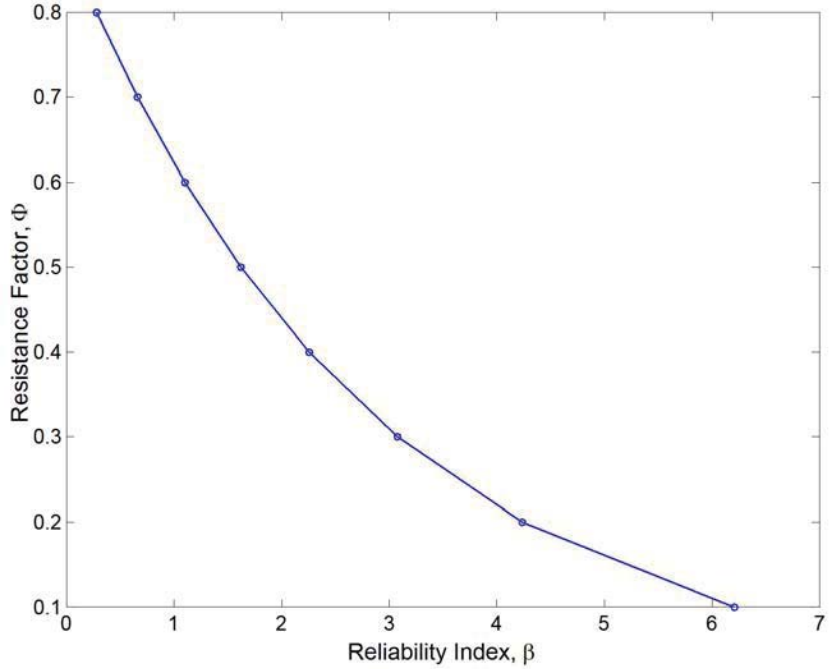


Figure B-25b Resistance Factor Calibration from 31 Concrete pile Cases in Mixed Soil in Louisiana by Using αAPI-Nordlund –Thurman Method

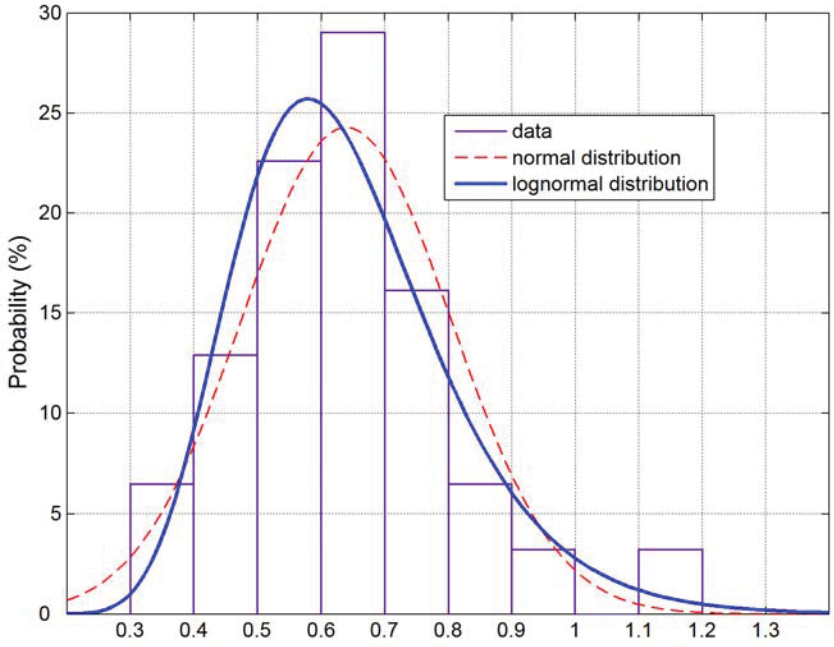


Figure B-26a Frequency Distribution for 31 Concrete Pile Cases in Mixed Soil in Louisiana by Using β-Thurman Method

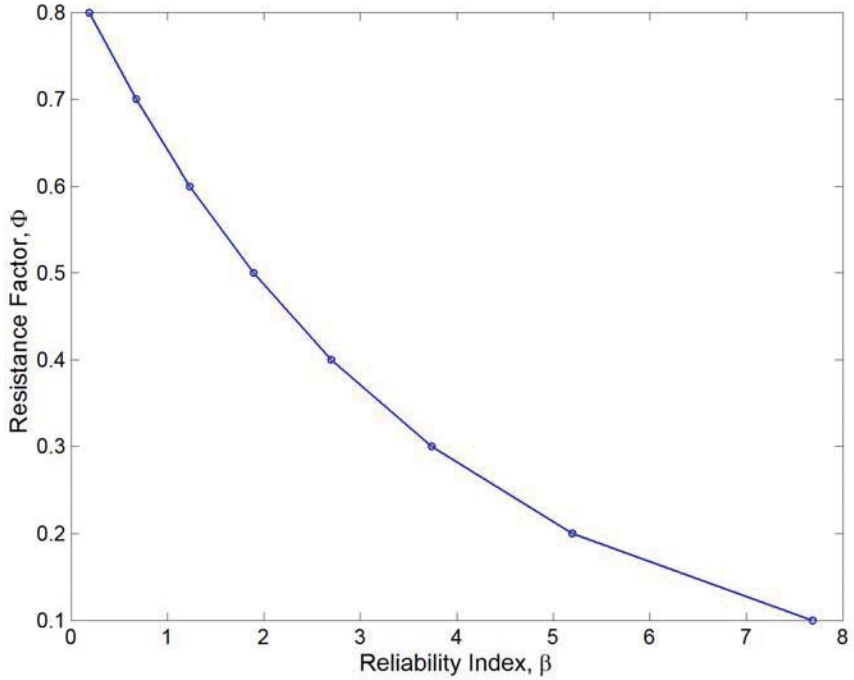
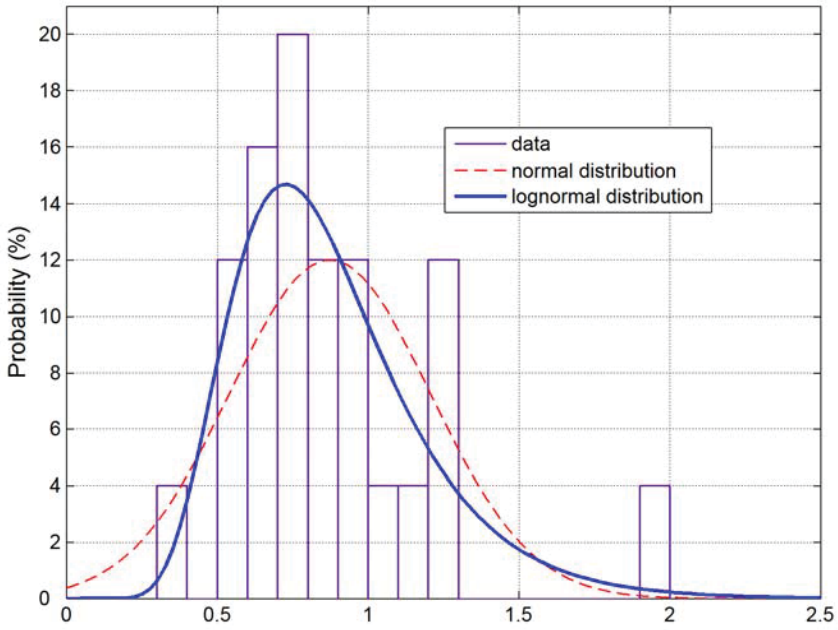


Figure B-26b Resistance Factor Calibration by FORM from 31 Concrete Pile Cases in mixed soil in Louisiana by Using β-Thurman Method



Rdavisson/R Schmertmann SPT

Figure B-27a Frequency Distribution for 25 Concrete Pile Cases in Mixed Soil in Louisiana by Using Schmertmann SPT Method

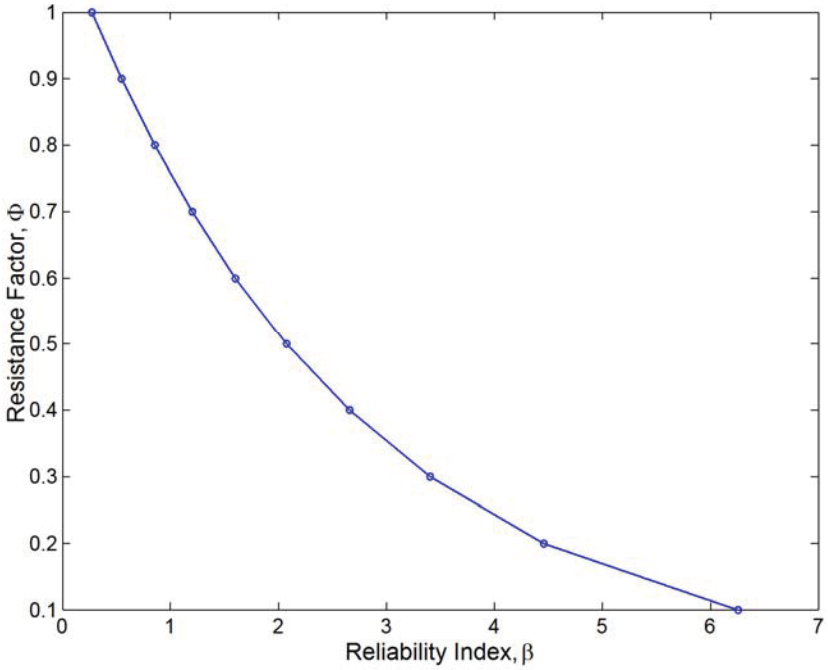


Figure B-27b Resistance Factor Calibration from 25 Concrete Pile Cases in Mixed Soil in Louisiana by Using Schmertmann SPT Method

APPENDIX C
Calibration Resistance Factor by Using FOSM for Driven Pile
using CAPWAP Method

Table C-1 Total CAPWAP (EOD+BOR) Data

No.	Pile-Case Number	Location	Pile Type	Penetr Depth (m)	Soil Type		Davisson's Criteria (kN)	Rdavission Rcapwap
					Side	Tip		
1	FN1-EOD	Omaha NE	HP1Ox42	21.95	silty clay	till	1352	1.322
2	FNI-BOR1	Omaha NE	HPIOx42	21.98	silty clay	till	1352	0.811
3	FN1-BOR2	Omaha NE	HPIOx42	22.25	silty clay	till	1352	0.705
4	FN2-EOD	Omaha NE	PSC12"sq	19.81	silty clay	till	1592	1.584
5	FN2-BOR	Omaha NE	PSC12"sq	19.81	silty clay	till	1592	1.173
6	FN3-EOD	Omaha NE	PSC14"sq	17.07	silty clay	till	1681	2.112
7	FN3-BOR	Omaha NE	PSC14"sq	17.07	silty clay	till	1681	1.273
8	FN4-EOD	Omaha NE	CEP12.75"	20.12	silty clay	till	1263	1.164
9	FN4-BOR	Omaha NE	CEP12.75"	20.12	silty clay	till	1263	0.986
10	FIA-EOD	Iowa	HP14x89	34.78	clayey sand	sand	4128	2.529
11	FIA-BOR	Iowa	HP14x89	34.78	clayey sand	sand	4128	1.269
12	FIB-EOD	Iowa	CEP 14"	28.68	clayey sand	sand	2891	1.272
13	FIB-BOR	Iowa	CEP 14"	28.68	clayey sand	sand	2891	1.247
14	FOl-EOD	Oklahoma	CEP 26"	18.35	silty sand	silty sand	2660	1.206
15	FO1-BOR	Oklahoma	CEP 26"	18.35	silty sand	silty sand	2660	0.854
16	FO2-EOD	Oklahoma	PSC24"oct	19.2	silty sand	silty sand	3381	1.434
17	FO2-BOR	Oklahoma	PSC24"oct	19.23	silty sand	silty sand	3381	1.040
18	FO3-EOD	Oklahoma	HP14x117	19.42	sa-si-clay	clayey sand	3452	1.371
19	FO4-EOD	Oklahoma	RC24"sq	13.72	sa-si-clay	clayey sand	7562	2.584
20	F04-BOR	Oklahoma	RC24"sq	17.01	sa-si-clay	clayey sand	7562	2.216
21	FOR1-EOD	Oregon	PSC20"sq	38.25	sand & silt	siltstone	6050	2.433
22	FORT-BOR	Oregon	PSC20"sq	38.28	sand & silt	siltstone	6050	1.866
23	FM5-EOD	Maine	CEP 18"	30.18	clay & sand	sand	1957	1.272
24	FM5-BOR	Maine	CEP 18"	30.21	clay & sand	sand	1957	0.882
25	FM17-EOD	Maine	CEP 18"	21.67	till	till	1815	0.962
26	FM17-BOR	Maine	CEP 18"	21.73	till	till	1815	0.776
27	FM23-EOD	Maine	CEP 18"	15.45	till	till	1521	1.058
28	FM23-BOR	Maine	CEP 18"	15.48	till	till	1521	1.006
29	FC1-EOD	Colorado	CEP12.75"	10.21	sand	sand	1406	1.171
30	FC1-BOR	Colorado	CEP12.75"	10.33	sand	sand	1406	1.193
31	FC2-EOD	Colorado	CEP12.75"	8.08	sand	sand	1637	0.981
32	FC2-BOR	Colorado	CEP12.75"	8.2	sand	sand	1637	1.083
33	FMI1-EOD	Missouri	CEP 14"	25.3	sand-gravel	sand	1468	1.158
34	FMI1-BOR	Missouri	CEP 14"	25.33	sand-gravel	sand	1468	1.035
35	FMI2-EOD	Missouri	CEP 14"	18.59	sand-gravel	sand	930	1.137
36	FMI2-BOR	Missouri	CEP 14"	18.59	sand-gravel	sand	930	0.964
37	FWA-EOD	Washingtn	CEP 48"	7.56	till-gravel	till	5783	4.408
38	FWA-BOR	Washingtn	CEP 48"	7.59	till-gravel	till	5783	1.994
39	FWB-EOD	Washingtn	CEP 48"	33.22	till-gravel	till	4448	
40	FWB-BOR	Washingtn	CEP 48"	33.31	till-gravel	till	4448	
41	FA1-EOD	Alabama	PSC 18"sq	19.51	silty sand	silty sand	1646	1.805
42	FA1-BOR1	Alabama	PSC 18"sq	19.66	silty sand	silty sand	1646	1.440
43	FAI-BOR2	Alabama	PSC 18"sq	19.75	silty sand	silty sand	1646	0.969

Table C-1 (cont.)

44	FA2-EOD	Alabama	PSC 18"sq	22.86	silty sand	silty sand	2447	1.285
45	FA2-BORI	Alabama	PSC 18"sq	22.95	silty sand	silty sand	2447	1.125
46	FA2-BOR2	Alabama	PSC 18"sq	23.01	silty sand	silty sand	2447	0.919
47	FA3-EOD	Alabama	PSC 24"sq	19.51	silty sand	silty sand	2780	1.839
48	FA3-BORI	Alabama	PSC 24"sq	19.54	silty sand	silty sand	2780	2.035
49	FA3-BOR2	Alabama	PSC 24"sq	19.66	silty sand	silty sand	2780	1.065
50	FA4-EOD	Alabama	PSC 24"sq	22.86	silty sand	silty sand	3634	1.832
51	FA4-BOR1	Alabama	PSC 24"sq	22.89	silty sand	silty sand	3634	1.352
52	FA4-BOR2	Alabama	PSC 24"sq	22.92	silty sand	silty sand	3634	0.959
53	FA5-EOD	Alabama	PSC 36"sq	22.25	silty sand	silty sand	5071	1.722
54	FA5-BOR	Alabama	PSC 36"sq	22.28	silty sand	silty sand	5071	1.206
55	FV15-EOD	Vermont	HP14x73	22.86	silt-d.sand	sand gravel	1401	1.623
56	FV15-BOR	Vermont	HP14x73	23.1	silt-d.sand	sand gravel	1401	1.590
57	FV10-EOD	Vermont	HP14x73	27.43	silt-d.sand	sand gravel	1535	2.171
58	FV10-BOR	Vermont	HP14x73	27.55	silt-d.sand	sand gravel	1535	1.928
59	FMN2-EOD	Minnesota	HP14x73	29.26	sa-si-clay	fat clay	3403	2.237
60	FMN2-BOR	Minnesota	HP14x73	29.29	sa-si-clay	fat clay	3403	1.173
61	FP5-EOD	Penn.	Monotube	7.19	sandy grvl	sandy grvl	1081	1.157
62	FP5-BOR	Penn.	Monotube	7.25	sandy grvl	sandy grvl	1081	1.017
63	FKG-EOD	Kentucky	PSC14"sq	10.58	soft clay	dense	1628	1.271
64	FKG-BOR	Kentucky	PSC14"sq	10.58	soft clay	dense	1628	1.241
65	FL3-EOD	Louisiana	PSC24"sq	25.69	silty clay	silty sand	1779	2.940
66	FL3-BORI	Louisiana	PSC24"sq	25.69	silty clay	silty sand	1779	1.470
67	FL3-BOR2	Louisiana	PSC24"sq	25.69	silty clay	silty sand	1779	1.143
68	CAI-EOD	O.S. Ont	CEP 9.6"	47.03	si-sa-clay	si-sa-till	2402	1.317
69	CA1-BOR	O.S. Ont	CEP 9.6"	47.03	si-sa-clay	si-sa-till	2402	1.080
70	CA2-BOR	O.S. Ont	CEP 9.6"	33.56	si-sa-clay	si-sa-clay	1628	1.070
71	CA5-BORI	N.Y. Ont	CEP11.73"	19.26	fill-sand	sand	2082	1.145
72	CA5-BOR2	N.Y. Ont	CEP11.73"	19.99	fill-sand	sand	2082	0.957
73	CA3/8-BOR	Bar. Ont	CEP10.24"	19.63	sand-silt	silt	841	0.785
74	CA24-BOR	Tor. Ont	CEP12.75"	11.77	sand	sand	1076	1.168
75	CA6-BOR1	Ham. Ont	CEP12.75"	16.46	sa-si-till	silt-till	2936	1.082
76	CA6-BOR2	Ham. Ont	CEP12.75"	16.46	sa-si-till	silt-till	2936	1.130
77	CA6-EOR	Ham. Ont	CEP12.75"	16.46	sa-si-till	silt-till	2936	1.183
78	WC3-EOD	Florida	PSC24"sq	8.32	Is.-d.sand	dense	2713	1.198
79	WC3-BORI	Florida	PSC24"sq	8.38	Is.-d.sand	dense	2713	1.205
80	WC3-BOR2	Florida	PSC24"sq	8.38	Is: d.sand	dense	2713	1.138
81	WC6-EOD	Florida	PSC24"sq	8.63	Is.-dsand	dense	2015	1.006
82	WC6-BOR1	Florida	PSC24"sq	8.69	ls.-d.sand	dense	2015	0.944
83	WC6-BOR2	Florida	PSC24"sq	8.38	Is.-d.sand	dense	2015	1.022
84	WB9-BOR	Florida	PSC30"sq	39.17	clayey sand	clayey	4003	0.956
85	WB15-BOR	Florida	PSC30"sq	31.58	sand	silt-clay	3648	1.019
86	T1/A-EOD	Israel	OEP 60"	16.09	clcr sand	sand	8825	1.118
87	T1/A-ALT	Israel	OEP 60"	16.4	cler sand	sand	8825	1.102
88	T1B-EOD	Israel	OEP 60"	31	clcr sand	sand	12749	1.211
89	T2/A-EOD	Israel	OEP 48"	16	cler sand	sand	5983	1.074
90	T2/B-EOD	Israel	OEP 48"	55.5	clcr sand	sand	14612	1.182
91	35-1-BOR	Toronto	HP12x74	14.78	cl-sa-silt	silty sand	1432	1.238

Table C-1 (cont.)

92	35-4-BOR	Toronto	CEP12.75"	14.69	cl-sa-silt	silty sand	1468	0.917
93	35-5-BOR	Toronto	HP12x74	27.58	cl-sa-silt	silty sand	2722	0.942
94	35-6-BOR	Toronto	CEP12.75"	27.43	cl-sa-silt	silty sand	2669	1.034
95	35-7-BOR	Toronto	T.Timber	12.68	cl-sa-silt	silty sand	543	0.879
96	35-10-BOR	Toronto	PSC 12"sq	14.63	cl-sa-silt	silty sand	1788	1.203
97	E2-BOR	Raleigh	PSC 12"sq	13.56	cl-sa-silt	cl-sa-silt	1846	0.988
98	63S-BOR	Penn.	HP12x53	20.12	sand-silt	silt	1263	1.018
99	LB21-BOR	NA	PSC 20"sq	10.97	silt-sand	silt-sand	1690	1.052
100	LB20-BOR	NA	PSC 20"sq	16.76	sand	sand	2580	1.224
101	LC3-BOR	NA	PSC 20"sq	26.21	cl-sa-silt	cl-sa-silt	2758	1.013
102	LIN16-BOR	NA	PSC 20"sq	28.65	cl-sa-silt	cl-sa-silt	2669	1.031
103	LE37-BOR	NA	PSC 10"sq	15.24	cl-sa-silt	limestone	1112	1.269
104	LE64-BOR	NA	PSC 10"sq	17.68	cl-sa-silt	sa-cl-silt	1201	1.164
105	ST1-EOD	Florida	PSC 18"sq	13.41		carb sand	1530	0.681
106	ST2-EOD	Florida	PSC 18"sq	12.19		carb sand	2269	0.828
107	ST9-BOR	Virginia	PSC 54"sq	33.22		silt-clay	4092	1.140
108	ST46-EOD	New York	CEP 10"	11.58	silt-sand	silt-sand		
109	GZA3-EOD	Prov. RI	CEP13.38"	38.25	silt-sand	gr-sa-silt	1957	1.205
110	GZA5-EOD	Prov. RI	CEP 9.75"	28.59	silt-sand	till-shale	1139	0.874
111	GZA6-EOD	Prov. RI	CEP 9.75"	47.55	silt-sand	gr-sa-silt	836	0.684
112	GZBBC-EOD	Prov. RI	CEP 10"	30.33	silt-sand	silt	1957	1.065
113	GZBP2-EOD	Prov. RI	CEP13.38"	32.31	silt-sand	gr-sa-silt	1246	0.884
114	GZB6-EOD	Prov. RI	CEP13.38"	28.13	silt-sand	si-sa-till	1690	1.114
115	GZZ5-EOD	Boston MA	CEP 14"	26.52	till-clay	till	2064	2.168
116	GZO5-EOD	Boston MA	CEP 14"	16.46	till-clay	till	2135	2.341
117	GZCC5-EOD	Boston MA	CEP 14"	24.38	till-clay	till	2002	0.915
118	GZL2-EOD	Boston MA	CEP 14"	25.3	till-clay	till	2847	2.396
119	GZP14-EOD	Boston MA	CEP 14"	18.44	till-clay	till	1735	1.279
120	GZP11-EOD	Boston MA	CEP 14"	17.22	till-clay	till	1112	1.046
121	GZP12-EOD	Boston MA	CEP 14"	21.03	till-clay	till	2224	0.962
122	GZB22-EOD	Colt Neck	OEP 36"	35.97	sand-clay	silt-clay	4982	1.010
123	GZW 1-EOR	Vermont	CP12.75"	30.33	silty sand	sand	1601	1.440
124	A54-EOD	Australia	RC10.8"sq	20.6	silty clay	clay	2900	1.702
125	A54-BOR	Australia	RC10.8"sq	20.6	silty clay	clay	2900	1.067
126	A147-EOD	Australia	RCI0.8"sq	20.6	silty clay	clay	2482	2.155
127	A147-BOR	Australia	RC10.8"sq	20.6	silty clay	clay	2482	0.989
128	GF19-EOD	Pgh. PA	HP1Ox42	15.09	grvl-snd-slt	shale	1468	0.829
129	GF110-EOD	Pgh. PA	HP12x74	15.15	grvl-snd-slt	shale	2224	1.094
130	GF222-EOD	Pgh. PA	HP12x74	18.62	grvl-snd-slt	shale	2580	1.133
131	GF224-EOD	Pgh. PA	Monotube	9.02	grvl-snd-slt	grvl-snd-slt		
132	GF312-EOD	Pgh. PA	HP12x74	8.6	snd-grvl-shl	shale	1512	0.839
133	GF313-EOD	Pgh. PA	HP10x57	9.6	snd-grvl-shl	claystone	1486	0.749
134	GF412-EOD	Pgh. PA	HP12x74	10.24	grvl-snd-slt	claystone	1068	0.528
135	GF413-EOD	Pgh. PA	HP10x57	10.55	grvl-snd-slt	claystone	1334	0.701
136	GF414-EOD	Pgh. PA	HPIOx57	10.58	grvl-snd-slt	claystone	1601	0.687
137	GF415-EOD	Pgh. PA	HP12x74	10.39	grvl-snd-slt	claystone	2046	0.820
138	EF62-EOD	Canada	CP 9.625"	18.99	si-sa-clay	till	2233	0.962
139	EF167-BOR	Canada	CP 9.625"	21	si-sa-clay	till	1205	0.565

Table C-1 (cont.)

140	A3-EOD2	Florida	VC 24"sq	27.52	clayey sand	sand	4261	2.603
141	A3-BOR2	Florida	VC 24"sq	27.55	clayey sand	sand	4261	2.073
142	A3-BOR3	Florida	VC 24"sq	27.61	clayey sand	clayey sand	4261	1.035
143	A14-DD1	Florida	VC 24"sq	13.72	sandy clay	sand		
144	A14-DD2	Florida	VC 24"sq	14.33	sandy clay	sand		
145	A14-BOR1	Florida	VC 24"sq	17.83	clayey sand	sand		
146	A14-BOR2	Florida	VC 24"sq	17.92	clayey sand	sand		
147	A25-EOD	Florida	VC 24"sq	16.79	clayey sand	sand	3180	1.557
148	A25-BOR1	Florida	VC 24"sq	16.82	clayey sand	sand	3180	1.288
149	A25-BOR2	Florida	VC 24"sq	16.89	clayey sand	sand	3180	1.581
150	A25-BOR3	Florida	VC 24"sq	16.92	clayey sand	sand	3180	1.617
151	AI6-EOD	Florida	PSC18"sq	18.47	sandy clay	sand	1401	1.407
152	A16-BOR1	Florida	PSC18"sq	18.47	sandy clay	sand	1401	1.117
153	A16-BOR2	Florida	PSC18"sq	18.59	sandy clay	sand	1401	1.064
154	A41-EOD	Florida	VC 24"sq	15.85	clay	sand	2331	1.216
155	A41-BOR1	Florida	VC 24"sq	15.85	clay	sand	2331	1.042
156	A41-BOR2	Florida	VC 24"sq	16.09	clay	sand	2331	0.928
157	A101-EOD	Florida	VC 24"sq	18.84	clay	clayey sand	3612	1.570
158	A101-BORI	Florida	VC 24"sq	18.84	clay	clayey sand	3612	1.214
159	A101-BOR2	Florida	VC 24"sq	18.93	clay	clayey sand	3612	1.011
160	A133-EOD	Florida	VC 24"sq	31.67	clayey sand	sandy clay	3594	2.599
161	A133-BOR	Florida	VC 24"sq	31.97	clayey sand	sandy clay	3594	1.036
162	A145-EOD	Florida	VC 24"sq	31.36	clayey sand	sand	4341	2.765
163	A145-BOR1	Florida	VC 24"sq	31.36	clayey sand	sand	4341	1.523
164	A145-BOR2	Florida	VC 24"sq	31.39	clayey sand	sand	4341	1.282
165	CB3-BOR	Florida	PSC24"sq	23.47	clayey sand	sand	2224	0.886
166	CB3-BORL	Florida	PSC24"sq	23.71	clayey sand	sand	2224	0.996
167	CB5-BOR	Florida	VC 30"sq	16.18	clayey sand	sand	5560	2.200
168	CB5-BORL	Florida	VC 30"sq	16.46	clayey sand	sandy clay	5560	2.140
169	CBI 1-BORL	Florida	VC 30"sq	26.12	clayey sand	clayey sand	6383	1.763
170	CB11-EORL	Florida	VC 30"sq	26.15	clayey sand	clayey sand	6383	2.246
171	CB17-BOR1	Florida	VC 30"sq	23.68	clayey sand	clayey sand	6739	1.847
172	CB17-BOR2	Florida	VC 30"sq	23.71	clayey sand	clayey sand	6739	2.023
173	CB17-BORL	Florida	VC 30"sq	23.74	clayey sand	clayey sand	6739	2.218
174	CB17-DRL	Florida	VC 30"sq	23.84	clayey sand	clayey sand	6739	1.793
175	CB23-BOR	Florida	VC 30"sq	24.48	clayey sand	sand	2860	1.039
176	CB23-BORE	Florida	VC30"sq	25.21	clayey sand	sand	2860	1.448
177	CB29-BORL	Florida	VC 30"sq	25.76	clayey sand	clayey sand	4079	1.182
178	CB29-EORL	Florida	VC 30"sq	25.76	clayey sand	clayey sand	4079	2.043
179	CB35-BOR1	Florida	VC 30"sq	23.93	clayey sand	clayey sand	6508	1.802
180	CB35-BOR2	Florida	VC 30"sq	24.05	clayey sand	clayey sand	6508	1.542
181	CB35-BORL	Florida	VC 30"sq	24.11	clayey sand	clayey sand	6508	1.610
182	CB41-EOR	Florida	VC 30"sq	19.72	sandy clay	sandy clay	6272	1.645
183	CB41-BOR	Florida	VC 30"sq	19.72	sandy clay	sandy clay	6272	1.659
184	CB41-BORL	Florida	VC 30"sq	19.93	sandy clay	sandy clay	6272	2.908
185	CB26-EOD	Florida	PSC24"sq	19.05	clayey sand	sand	4270	1.967
186	CB26-BOR	Florida	PSC24"sq	19.08	clayey sand	sand	4270	1.551
187	CB26-EOR	Florida	PSC24"sq	19.75	clayey sand	sandy clay	4270	1.341

Table C-1 (cont.)

188	CB26-BOR2	Florida	PSC24"sq	19.81	sandy clay	sandy clay	4270	1.705
189	33P1-EOD	Ontario	HP 12x74	34.87	cl-sa-silt	silty sand	3559	1.822
190	33P1-BOR	Ontario	HP 12x74	34.87	cl-sa-silt	silty sand	3559	1.119
191	33P1-EOR	Ontario	HP 12x74	34.87	cl-sa-silt	silty sand	3559	1.231
192	33P2-EOD	Ontario	CP 12.75"	32.67	cl-sa-silt	silty sand	2180	1.690
193	33P2-BOR	Ontario	CP 12.75"	32.67	cl-sa-silt	silty sand	2180	1.381
194	33P2-EOR	Ontario	CP 12.75"	32.67	cl-sa-silt	silty sand	2180	1.222
195	33P4-EOD	Ontario	PSC 12"sq	16.52	cl-sa-silt	cl-silt-till	2073	1.165
196	33P5-EOD	Ontario	#14 Timber	8.66	cl-sa-silt	cl-silt-till	730	1.148
197	TRD22-EOD	Ontario	HP 12x74	6.13	sand	till	1575	0.819
198	TRD22-BOR	Ontario	HP 12x74	6.13	sand	till	1575	1.204
199	TRE22-EOD	Ontario	HP 12x74	7.83	sand	rock	2473	0.967
200	TRE22-BOR	Ontario	HP 12x74	7.83	sand	rock	2473	0.903
201	TRP5X-EOD	Ontario	HP 12x53	7.68	sand	rock	1824	0.847
202	TRP5X-BOR	Ontario	HP 12x53	7.68	sand	rock	1824	1.038
203	TR131-BOR	Ontario	CP 7.063"	NA	sand	rock	623	0.844
204	TRAH-EOR	Brunswick	HP 12x89	38.4	clayey silt	sandy gravel	3247	3.347
205	TRBH-BOR	Brunswick	HP 12x89	31.12	clayey silt	sandy gravel	1446	3.249
206	TRBP-EOR	Brunswick	CP 12.75"	31.7	clayey silt	sandy gravel	1512	1.371
207	CHAT-EOD	Wisconsin	CEP 12.75"	37.49	sa-si clay	silty sand	2909	1.677
208	CHAT-BOR1	Wisconsin	CEP 12.75"	37.52	sa-si clay	silty sand	2909	1.407
209	CHA1-BOR2	Wisconsin	CEP 12.75"	37.52	sa-si clay	silty sand	2909	1.263
210	CHA4-EOD	Wisconsin	CEP 12.75"	35.66	sa-si clay	silty sand	2251	1.868
211	CHB2-EOD	Wisconsin	HP12x63	47.34	sa-si clay	silty sand	1343	2.746
212	CHB2-BOR1	Wisconsin	HP12x63	47.34	sa-si clay	silty sand	1343	1.118
213	CHB2-BOR3	Wisconsin	HP12x63	47.4	sa-si clay	silty sand	1343	0.888
214	CHB2-BOR4	Wisconsin	HP12x63	47.43	sa-si clay	silty sand	1343	0.671
215	CHB2-BOR5a	Wisconsin	HP12x63	47.46	sa-si clay	silty sand	1343	0.586
216	CHB2-BOR5b	Wisconsin	HP12x63	47.46	sa-si clay	silty sand	1343	0.632
217	CHB3-EOD	Wisconsin	HP12x63	43.31	sa-si clay	silty sand	890	1.906
218	CHB3-BOR1	Wisconsin	HP12x63	43.31	sa-si clay	silty sand	890	0.852
219	CHB3-BOR2	Wisconsin	HP12x63	43.43	sa-si clay	silty sand	890	0.909
220	CHB3-BOR3	Wisconsin	HP12x63	43.53	sa-si clay	silty sand	890	0.597
221	CHC3-EOD	Wisconsin	CEP14"	47.3	sa-si clay	silty sand	836	1.710
222	CHC3-BOR	Wisconsin	CEP14"	47.3	sa-si clay	silty sand	836	
223	CHC3-BORL	Wisconsin	CEP14"	47.34	sa-si clay	silty sand	836	0.482
224	CH4-EOD	Wisconsin	CEP9.63"	43.43	silty clay		1601	2.400
225	CH4-BOR	Wisconsin	CEP9.63"	43.43	silty clay		1601	1.059
226	CH39-EOD	Wisconsin	CEP9.63"	43.28	silty clay	silty clay	2936	3.529
227	CH39-BOR	Wisconsin	CEP9.63	43.28	silty clay	silty clay	2936	1.435
228	CH39-BORL	Wisconsin	CEP9.63"	43.37	silty clay	silty clay	2936	1.148
229	CH6-5B-EOD	Wisconsin	CEP9.63"	43.89	silty clay	silty sand	1673	
230	CH6-5B-BOR	Wisconsin	CEP9.63"	43.89	silty clay	silty sand	1673	0.940
231	CH95B-EOD	Wisconsin	CEP9.63"	42.37	silty clay	sand & grvl	2473	2.516

Table C-1 (cont.)

232	CH95B-BOR	Wisconsin	CEP9.63"	42.37	silty clay	sand & grvl	2473	1.049
233	CH256-BOR3	Wisconsin	CEP9.63"	42.67	si-sa clay	si-sa & grvl	2651	1.192
234	CH351-BOR2	Wisconsin	CEP9.63"	47.55	si-sa clay	si-sa & grvl	2669	1.132
235	PO2-BOR1	Florida	PSC18"sq	5.73	sand	dense sand	1219	0.902
236	PO2-BOR2	Florida	PSC18"sq	6.07	sand	dense sand	1219	1.038
237	PO2-BORL	Florida	PSC18"sq	6.28	sand	dense sand	1219	0.975
238	PO19-BOR	Florida	PSC18"sq	4.63	sand	dense sand	1023	0.767
239	PO19-EOD	Florida	PSC18"sq	5.24	sand	dense sand	1023	0.939
240	PO19-EORL	Florida	PSC18"sq	5.36	sand	dense sand	1023	0.979
241	ER5-BOR1	Florida	PSC24"sq	25.97	sand	sand	3803	1.299
242	ER5-BOR2	Florida	PSC24"sq	26.03	sand	sand	3803	0.922
243	ER5-BORL	Florida	PSC24"sq	26.15	sand	sand	3803	1.457
244	ER77-BOR	Florida	PSC24"sq	18.56	clayey sand	cl-si-sand	7433	2.210
245	ER77-BORL	Florida	PSC24"sq	18.68	clayey sand	cl-si-sand	7433	1.658
246	BB13-EOD	Florida	VC 30"sq	28.29	clayey sand	sand	4475	1.437
247	BB13-BOR1a	Florida	VC 30"sq	28.32	clayey sand	sand	4475	1.094
248	BB13-BORIb	Florida	VC 30"sq	28.32	clayey sand	sand	4475	1.130
249	BB 13-BOR2a	Florida	VC 30"sq	28.71	clayey sand	sand	4475	0.940
250	BB13-BOR2b	Florida	VC 30"sq	28.71	clayey sand	sand	4475	0.958
251	BB I3-BORL	Florida	VC 30"sq	28.8	clayey sand	sand	4475	1.117
252	BB19-BORa	Florida	VC 30"sq	27.13	sand	sand	5169	1.244
253	BB19-BORb	Florida	VC 30"sq	27.13	sand	sand	5169	1.108
254	BB19-BORL	Florida	VC 30"sq	27.19	sand	sand	5169	0.794
255	BB24-EOD	Florida	VC 30"sq	24.44	sand	clay	4955	0.857
256	BB24-BOR1a	Florida	VC 30"sq	24.48	sand	clay	4955	0.659
257	BB24-BORIb	Florida	VC 30"sq	24.48	sand	clay	4955	0.654
258	BB24-BOR2a	Florida	VC 30"sq	24.63	sand	clay	4955	0.588
259	I31324-BOR2b	Florida	VC 30"sq	24.63	sand	clay	4955	0.629
260	BB24-BORL	Florida	VC 30"sq	24.69	sand	clay	4955	0.794
261	BB29-BOR	Florida	VC 30"sq	23.90 -	sand	sand	5053	0.926
262	BB29-BORL	Florida	VC 30"sq	23.96	sand	sand	5053	0.988
263	ABF6-BOR	Florida	PSC 24" sq	17.54	si/clayey sand	clayey sand	3345	1.995
264	ABF6-BORL	Florida	PSC 24" sq	17.84	si/clayey sand	clayey sand	3345	0.963
265	ABG13-BORL	Florida	PSC 24" sq	14.08	clayey sand	limestone	4742	0.983
266	ABH2-BOR	Florida	PSC 24" sq	10.9	silt/silty clay	limestone	2518	0.701
267	ABH2-BORL	Florida	PSC 24" sq	10.96	silt/silty clay	limestone	2518	0.615
268	BC79-EOD	S.Carolina	PSC 24" oct	23.47	si-cl-sand	calcar sand	2277	
269	BC79-BORL	S.Carolina	PSC 24" oct	23.5	si-cl-sand	calcar sand	2277	0.931
270	BC64-EOD	S.Carolina	PSC 24" oct	18.59	si-cl-sand	calcar sand	5071	
271	BC64-BORL	S.Carolina	PSC 24" oct	18.62	si-cl-sand	calcar sand	5071	1.013
272	DI-BORI	Holland	PSC 9.7"sq	10.91	clay-sand	sand	302	0.714

Table C-1 (cont.)

273	D2-BOR1	Holland	PSC 9.7"sq	14.3	clay-sand	clay	556	0.850
274	D3-BORa	Holland	PSC 9.7"sq	18.29	clay-sand	sand	1005	1.229
275	D3-BORb	Holland	PSC 9.7"sq	18.29	clay-sand	sand	1005	1.448
276	D5-BORa	Holland	PSC 9.7"sq	18.29	clay-sand	sand	1050	0.787
277	D5-BORb	Holland	PSC 9.7"sq	18.29	clay-sand	sand	1050	0.797
278	MB1-EOD	S. Carolina	PSC 16"sq	18.9	sand	silty sand	3590	4.749
279	MB1-BOR	S. Carolina	PSC 16"sq	19.2	sand	silty sand	3590	1.543
280	MB2-BOR	S. Carolina	HP14x89	20.12	silty sand	calcar. silt	3990	1.689
281	MB3-BOR	S. Carolina	OEP 16"	20.12	silty sand	calcar. silt	4146	1.632
282	S1-EOD	S. Carolina	OEP 24"	24.84	clayey sand	sandy silt	2651	1.296
283	SI-BOR	S. Carolina	OEP 24"	24.84	clayey sand	sandy silt	2651	0.987
284	S2-EOD	S. Carolina	HP14x73	23.77	clayey sand	sandy silt	1415	1.480
285	S2-BOR	S. Carolina	HP14x73	23.77	clayey sand	sandy silt	1415	1.036
286	DD22-EOD	Florida	PSC 14"sq	27.43	clay	sand	3745	3.302
287	DD22-BOR	Florida	PSC 14"sq	27.74	clay	sand	3745	1.622
288	DD23-EOD	Florida	CEP 12.75	24.99	clay	sand	2206	3.239
289	DD23-BOR	Florida	CEP 12.75	25.09	clay	sand	2206	1.791
290	JR17-EOD	Richmond, VA	PSC 24" sq	10.76	cl-si-sand	silty sand	5422	1.947
291	LB3-EOD	Kenner, LA	PSC 24" sq	24.84	clay	Sand	1842	6.848
292	LB3-BOR1	Kenner, LA	PSC 24" sq	24.99	clay	Sand	1842	2.020
293	LB3-BOR2	Kenner, LA	PSC 24" sq	24.99	clay	Sand	1842	1.201
294	LB3-BOR3	Kenner, LA	PSC 24" sq	24.99	clay	Sand	1842	1.098
295	LB4-EOD	Kenner, LA	PSC 30" sq	24.99	clay	Sand	2273	11.252
296	LB4-BOR1	Kenner, LA	PSC 30" sq	25.21	clay	Sand	2273	2.563
297	LB4-BOR2	Kenner, LA	PSC 30" sq	25.27	clay	Sand	2273	1.750
298	LB4-BOR3	Kenner, LA	PSC 30" sq	25.3	clay	Sand	2273	1.494
299	LB4-BOR4	Kenner, LA	PSC 30" sq	25.3	clay	Sand	2273	1.418
300	LB5-EOD	Kenner, LA	PSC 30" sq	24.99	clay	Sand		
301	LB5-BOR1	Kenner, LA	PSC 30" sq	24.99	clay	Sand		
302	LB5-BOR2	Kenner, LA	PSC 30" sq	24.99	clay	Sand		
303	LB5-BOR3	Kenner, LA	PSC 30" sq	25.3	clay	Sand		
304	LB5-BOR4	Kenner, LA	PSC 30" sq	25.3	clay	Sand		
305	LB6-EOD	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2411	5.968
306	LB6-BOR1	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2411	2.730
307	LB6-BOR2	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2411	1.824
308	LB6-BOR3	Kenner, LA	PSC 36" cyl	24.99	clay	Sand	2411	1.364
309	LB6-BOR4	Kenner, LA	PSC 36" cyl	24.99	clay	Sand	2411	1.048
310	LB7-EOD	Kenner, LA	PSC 36" cyl	24.6	clay	Sand	2402	5.256
311	LB7-BOR1	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	2.745
312	LB7-BOR2	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	1.878
313	LB7-BOR3	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	1.270
314	LB7-BOR4	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	1.063
315	DI221-EOD	Massachusetts	PSC 14" sq	19.2	sa-si-clay	fine sand & silt	1477	
316	DI221-2DR	Massachusetts	PSC 14" sq	19.2	sa-si-clay	fine sand & silt	1477	1.182
317	TW488-EOD	Massachusetts	PSC 14" sq	23.16	stiff clay	stiff clay	1423	3.899

Table C-1 (cont.)

318	TW488-3DR	Massachusetts	PSC 14" sq	23.16	stiff clay	stiff clay	1423	1.524
319	NBTP2-EOD	Massachusetts	HP12X74	34.14	si-sa-clay	glacial till	1806	1.336
320	NBTP2-1DR	Massachusetts	HP12X74	34.14	si-sa-clay	glacial till	1806	1.128
321	NBTP2-6DR	Massachusetts	HP12X74	34.14	si-sa-clay	glacial till	1806	1.071
322	NBTP3-EOD	Massachusetts	HP12X74	33.07	si-sa-clay	silty	2126	1.517
323	NBTP3-1DR	Massachusetts	HP12X74	33.07	si-sa-clay	silty	2126	1.328
324	NBTP3-6DR	Massachusetts	HP12X74	33.07	si-sa-clay	silty	2126	1.241
325	NBTP5-EOD	Massachusetts	CEP12.75"	33.83	si-sa-clay	glacial till	1632	1.147
326	NBTP5-3DR	Massachusetts	CEP12.75"	33.83	si-sa-clay	glacial till	1632	0.798
327	PR1-BOR1	Virginia	PSC 24" sq	31.88	sand & silt	silty sand		
328	DD29-EOD	Florida	CEP 12.75"	49.68	clayey sand	clayey sand		
329	ND50-BOR1	Ohio	CEP 12"	6.71	silty clay	si-clayey sand	676	0.849
330	NZ12-BOR1	Mississippi	HP14X73	11.89	silt	silt	2224	0.954
331	DWI-BOR1	S. Carolina	PSC 24" sq	27.46	silty clay	silty clay	4742	1.050
332	DW 1-BOR2	S. Carolina	PSC 24" sq	27.52	silty clay	silty clay	4742	0.916
333	DW2-BORI	S. Carolina	HP14X73	27.46	si-sa-clay	silty clay	2753	0.984
334	DW2-BOR2	S. Carolina	HP14X73	27.52	si-sa-clay	silty clay	2753	0.910
335	DS1-BORI	S. Carolina	PSC 12" sq	26.82	cl-si-sand	calcar sand	1601	1.319
336	DS1-BOR2	S. Carolina	PSC 12" sq	26.85	cl-si-sand	calcar sand	1601	1.043
337	PX2-BOR1	Arizona	HP14X117	14.02	clay & sand	sa-gr-cobble		
338	PX3-EOD	Arizona	HP14XI 17	15.24	clay & sand	sa-gr-cobble		
339	PX3-BOR1	Arizona	HP14X117	15.24	clay & sand	sa-gr-cobble		
340	PX4-EOD	Arizona	CEP 14"	6.83	clay & sand	clayey sand	3207	1.419
341	PX4-BOR1	Arizona	CEP 14"	6.83	clay & sand	clayey sand	3207	1.145
342	PX5-BORI	Arizona	CEP 14"	7.53	clay & sand	clayey sand	2971	1.081
343	PX6-BOR1	Arizona	PSC 16" sq	7.01	clay & sand	clayey sand	4235	1.760
344	PX7-EOD	Arizona	PSC 16" sq	6.1	clay & sand	clay	4475	1.902
345	PX7-BOR1	Arizona	PSC 16" sq	6.1	clay & sand	clay	4475	1.623
346	CHI1-42-BOR1	Wisconsin	CEP 12.75"	28.99	sa-cl-silt	silty clay	1948	0.829
347	SSTPD-BOR	Sweden	PSC 9.25" sq	12.8	silty sand	silty sand	285	0.733
348	TSWID62/1-EOD	Hong Kong	PSC 19.69" cyl	22.7	sa-cl-silt	sandy silt	4359	1.298
349	TSW/D62/1-BOR	Hong Kong	PSC 19.69" cyl	22.7	sa-cl-silt	sandy silt	4359	0.917
350	TSW/HHK9/1-EOD	Hong Kong	PSC 19.69" cyl	23.6	sa-cl-silt	sandy silt	4604	1.208
351	TSW/HHK9/1-BOR	Hong Kong	PSC 19.69" cyl	23.6	sa-cl-silt	sandy silt	4604	0.949
352	TSW/D62/2-EOD	Hong Kong	HP12X120?	29.7	sa-cl-silt	sandy silt	4737	0.976

Table C-1 (cont.)

353	TSW/D62/2-BOR	Hong Kong	HP12X120?	29.7	sa-cl-silt	sandy silt	4737	1.020
354	TSW/ IHK9/2-EOD	Hong Kong	HP12X120?	31.5	sa-cl-silt	sandy silt	4804	1.141
355	TSW/HHK9/ 2-BOR	Hong Kong	HP12X120?	31.5	sa-cl-silt	sandy silt	4804	1.104
356	OD1J-EOD	Oakland, CA	OEP 24"	8.47	silty sand	silty clayey sand	7722	2.209
357	OD2P-EOD	Oakland, CA	OEP 24"	12.19	silty sand	silty sandy clay	3047	1.957
358	OD2P-BOR	Oakland, CA	OEP 24"	12.19	silty sand	silty sandy clay	3047	1.370
359	OD2T-EOD	Oakland, CA	CEP 24"	10.67	silty sand	silty sand & clay	3616	0.995
360	OD3H-EOD	Oakland, CA	OEP 42"	30.63	stiff clay	clay w/ sa-si-gr	4639	3.219
361	OD4L-EOD	Oakland, CA	CEP 24"	19.51	sandy clay	silty sandy clay	4399	1.962
362	OD4P-EOD	Oakland, CA	CEP 24"	17.07	silty clay	silty sandy clay	3087	2.543
363	OD4P-BOR	Oakland, CA	CEP 24"	17.07	silty clay	silty sandy clay	3087	1.257
364	OD4T-EOD	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3229	2.412
365	OD4T-BOR	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3229	1.117
366	OD4W-EOD	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3937	2.229
367	OD4W-BOR2	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3937	1.534
368	OD4W-BOR3	Oakland, CA	CEP 24"	18.38	sandy clay	silty sandy clay	3937	1.157
369	QC3-EOD	New York	PSC 54" cyl	23.01	sand	dense sand	6361	3.530
370	QC3-14DR	New York	PSC 54" cyl	23.01	sand	dense sand	6361	1.222
371	QC14-EOD	New York	PSC 14" cyl	22.86	sand	dense sand	1392	1.122
372	QC 14-30DR	New York	PSC 14" cyl	22.86	sand	dense sand	1392	1.163
373	NYSP-EOD	New York	HP1 OX42	33.5	silty sand	silty sand w/gr	1388	2.365
374	NYSP-BOR	New York	HP 10X42	33.5	silty sand	silty sand w/gr	1388	1.399
375	UFSSIA - BOR	Florida	PSC 24" sq	15	cl-si-sand	silty clay	3496	0.644
376	UFSSIB - BOR	Florida	PSC 20" sq	14.42	cl-si-sand	silty clay	2611	0.735
377	UFSS I O - BOR	Florida	PSC 24" sq	8.5	sa-si-clay	silty clay	5107	0.820
378	UFSS13B - BOR	Florida	PSC 24" sq	8.2	sa-si-clay	silty clay	2771	0.656
379	BIT20 - BOR	Florida	PSC 20" sq	14.08	silty sand	sand	2593	1.230
381	HFLS3 - EOD	Florida	PSC 30" sq	12.07	sa-si-clay	sandy clay	7073	1.222
382	HFLS4L -	Florida	PSC 30" sq	22.4	cl-si-limestone-	limerock	3354	1.070

	EOD				sand			
383	HFLS4L - BOR	Florida	PSC 30" sq	22.4	cl-si-limestone-sand	limerock	3354	0.824
384	RBA30 - BOR	Florida	PSC 30" sq	16.28	silty sand	silty sand	4039	1.094
385	RBB30W - BOR	Florida	PSC 30" sq	13.35	silty sand	silty sand	3461	1.073
386	CC6 - BOR	Florida	PSC 18" sq	16.18	silty sand	sand	1388	0.975
387	CC7 - BOR	Florida	PSC 14" sq	23.23	cl-si-sand	silty sand	1770	0.978
388	CC14 - BOR	Florida	PSC 14" sq	21.18	cl-si-sand	silty sand	1601	0.847
389	49SB37 - EOD	Florida	PSC 30" sq	7.13	sandy clay	silty limestone	5058	1.109

	N	**365**
	Average	**1.426**
	SD	**0.912**
	COV	**0.639**
Φ	**β=2.33**	**0.386**
	β=3.0	**0.254**

Table C-2 Alabama CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
41	FA1-EOD	Alabama	PSC 18"sq	19.51	silty sand	silty sand	1646	912	1.805
42	FA1-BOR1	Alabama	PSC 18"sq	19.66	silty sand	silty sand	1646	1143	1.440
43	FAI-BOR2	Alabama	PSC 18"sq	19.75	silty sand	silty sand	1646	1699	0.969
44	FA2-EOD	Alabama	PSC 18"sq	22.86	silty sand	silty sand	2447	1904	1.285
45	FA2-BORI	Alabama	PSC 18"sq	22.95	silty sand	silty sand	2447	2175	1.125
46	FA2-BOR2	Alabama	PSC 18"sq	23.01	silty sand	silty sand	2447	2664	0.919
47	FA3-EOD	Alabama	PSC 24"sq	19.51	silty sand	silty sand	2780	1512	1.839
48	FA3-BORI	Alabama	PSC 24"sq	19.54	silty sand	silty sand	2780	1366	2.035
49	FA3-BOR2	Alabama	PSC 24"sq	19.66	silty sand	silty sand	2780	2611	1.065
50	FA4-EOD	Alabama	PSC 24"sq	22.86	silty sand	silty sand	3634	1984	1.832
51	FA4-BOR1	Alabama	PSC 24"sq	22.89	silty sand	silty sand	3634	2687	1.352
52	FA4-BOR2	Alabama	PSC 24"sq	22.92	silty sand	silty sand	3634	3790	0.959
53	FA5-EOD	Alabama	PSC 36"sq	22.25	silty sand	silty sand	5071	2945	1.722
54	FA5-BOR	Alabama	PSC 36"sq	22.28	silty sand	silty sand	5071	4204	1.206

	N	**14**
	Average	**1.397**
	SD	**0.383**
	COV	**0.274**
Φ	**β=2.33**	**0.828**
	β=3.0	**0.656**

Table C-3 Oakland, CA CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
356	OD1J-EOD	Oakland, CA	OEP 24"	8.47	silty sand	silty clayey sand	7722	3496	2.209
357	OD2P-EOD	Oakland, CA	OEP 24"	12.19	silty sand	silty sandy clay	3047	1557	1.957
358	OD2P-BOR	Oakland, CA	OEP 24"	12.19	silty sand	silty sandy clay	3047	2224	1.370
359	OD2T-EOD	Oakland, CA	CEP 24"	10.67	silty sand	silty sand & clay	3616	3634	0.995
360	OD3H-EOD	Oakland, CA	OEP 42"	30.63	stiff clay	clay w/ sa-si-gr	4639	1441	3.219
361	OD4L-EOD	Oakland, CA	CEP 24"	19.51	sandy clay	silty sandy clay	4399	2242	1.962
362	OD4P-EOD	Oakland, CA	CEP 24"	17.07	silty clay	silty sandy clay	3087	1214	2.543
363	OD4P-BOR	Oakland, CA	CEP 24"	17.07	silty clay	silty sandy clay	3087	2455	1.257
364	OD4T-EOD	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3229	1339	2.412
365	OD4T-BOR	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3229	2891	1.117
366	OD4W-EOD	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3937	1766	2.229
367	OD4W-BOR2	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3937	2567	1.534
368	OD4W-BOR3	Oakland, CA	CEP 24"	18.38	sandy clay	silty sandy clay	3937	3403	1.157
								N	**13**
								Average	**1.843**
								SD	**0.671**
								COV	**0.364**
								Φ β=2.33	**0.908**
								β=3.0	**0.688**

Table C-4 South Carolina CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
268	BC79-EOD	S.Carolina	PSC 24" oct	23.47	si-cl-sand	calcar sand	2277		
269	BC79-BORL	S.Carolina	PSC 24" oct	23.5	si-cl-sand	calcar sand	2277	2447	0.931
270	BC64-EOD	S.Carolina	PSC 24" oct	18.59	si-cl-sand	calcar sand	5071		
271	BC64-BORL	S.Carolina	PSC 24" oct	18.62	si-cl-sand	calcar sand	5071	5004	1.013
278	MB1-EOD	S. Carolina	PSC 16"sq	18.9	sand	silty sand	3590	756	4.749
279	MB1-BOR	S. Carolina	PSC 16"sq	19.2	sand	silty sand	3590	2326	1.543
280	MB2-BOR	S. Carolina	HP14x89	20.12	silty sand	calcar. silt	3990	2362	1.689
281	MB3-BOR	S. Carolina	OEP 16"	20.12	silty sand	calcar. silt	4146	2540	1.632
282	S1-EOD	S. Carolina	OEP 24"	24.84	clayey sand	sandy silt	2651	2046	1.296
283	SI-BOR	S. Carolina	OEP 24"	24.84	clayey sand	sandy silt	2651	2687	0.987
284	S2-EOD	S. Carolina	HP14x73	23.77	clayey sand	sandy silt	1415	956	1.480
285	S2-BOR	S. Carolina	HP14x73	23.77	clayey sand	sandy silt	1415	1366	1.036
331	DWI-BOR1	S. Carolina	PSC 24" sq	27.46	silty clay	silty clay	4742	4515	1.050
332	DW 1-BOR2	S. Carolina	PSC 24" sq	27.52	silty clay	silty clay	4742	5178	0.916
333	DW2-BORI	S. Carolina	HP14X73	27.46	si-sa-clay	silty clay	2753	2798	0.984
334	DW2-BOR2	S. Carolina	HP14X73	27.52	si-sa-clay	silty clay	2753	3025	0.910

Table C-4 (cont.)

335	DS1-BORI	S. Carolina	PSC 12" sq	26.82	cl-si-sand	calcar sand	1601	1214	1.319
336	DS1-BOR2	S. Carolina	PSC 12" sq	26.85	cl-si-sand	calcar sand	1601	1535	1.043
								N	**16**
								Average	**1.411**
								SD	**0.930**
								COV	**0.659**
								Φ **β=2.33**	**0.306**
								β=3.0	**0.199**

Table C-5 Florida CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
78	WC3-EOD	Florida	PSC24"sq	8.32	Is.-d.sand	dense	2713	2264	1.198
79	WC3-BORI	Florida	PSC24"sq	8.38	Is.-d.sand	dense	2713	2251	1.205
80	WC3-BOR2	Florida	PSC24"sq	8.38	Is: d.sand	dense	2713	2384	1.138
81	WC6-EOD	Florida	PSC24"sq	8.63	Is.-dsand	dense	2015	2002	1.006
82	WC6-BOR1	Florida	PSC24"sq	8.69	ls.-d.sand	dense	2015	2135	0.944
83	WC6-BOR2	Florida	PSC24"sq	8.38	Is.-d.sand	dense	2015	1971	1.022
84	WB9-BOR	Florida	PSC30"sq	39.17	clayey sand	clayey	4003	4186	0.956
85	WB15-BOR	Florida	PSC30"sq	31.58	sand	silt-clay	3648	3581	1.019
105	ST1-EOD	Florida	PSC 18"sq	13.41		carb sand	1530	2246	0.681
106	ST2-EOD	Florida	PSC 18"sq	12.19		carb sand	2269	2740	0.828
140	A3-EOD2	Florida	VC 24"sq	27.52	clayey sand	sand	4261	1637	2.603
141	A3-BOR2	Florida	VC 24"sq	27.55	clayey sand	sand	4261	2055	2.073
142	A3-BOR3	Florida	VC 24"sq	27.61	clayey sand	clayey sand	4261	4115	1.035
143	A14-DD1	Florida	VC 24"sq	13.72	sandy clay	sand	NA	3043	
144	A14-DD2	Florida	VC 24"sq	14.33	sandy clay	sand	NA	3296	
145	A14-BOR1	Florida	VC 24"sq	17.83	clayey sand	sand	NA	2687	
146	A14-BOR2	Florida	VC 24"sq	17.92	clayey sand	sand	NA	4279	
147	A25-EOD	Florida	VC 24"sq	16.79	clayey sand	sand	3180	2042	1.557
148	A25-BOR1	Florida	VC 24"sq	16.82	clayey sand	sand	3180	2469	1.288
149	A25-BOR2	Florida	VC 24"sq	16.89	clayey sand	sand	3180	2011	1.581
150	A25-BOR3	Florida	VC 24"sq	16.92	clayey sand	sand	3180	1966	1.617
151	AI6-EOD	Florida	PSC18"sq	18.47	sandy clay	sand	1401	996	1.407
152	A16-BOR1	Florida	PSC18"sq	18.47	sandy clay	sand	1401	1254	1.117
153	A16-BOR2	Florida	PSC18"sq	18.59	sandy clay	sand	1401	1317	1.064
154	A41-EOD	Florida	VC 24"sq	15.85	clay	sand	2331	1917	1.216
155	A41-BOR1	Florida	VC 24"sq	15.85	clay	sand	2331	2237	1.042
156	A41-BOR2	Florida	VC 24"sq	16.09	clay	sand	2331	2513	0.928
157	A101-EOD	Florida	VC 24"sq	18.84	clay	clayey sand	3612	2300	1.570
158	A101-BORI	Florida	VC 24"sq	18.84	clay	clayey sand	3612	2976	1.214
159	A101-BOR2	Florida	VC 24"sq	18.93	clay	clayey sand	3612	3572	1.011
160	A133-EOD	Florida	VC 24"sq	31.67	clayey sand	sandy clay	3594	1383	2.599
161	A133-BOR	Florida	VC 24"sq	31.97	clayey sand	sandy clay	3594	3470	1.036
162	A145-EOD	Florida	VC 24"sq	31.36	clayey sand	sand	4341	1570	2.765

Table C-5 (cont.)

163	A145-BOR1	Florida	VC 24"sq	31.36	clayey sand	sand	4341	2851	1.523
164	A145-BOR2	Florida	VC 24"sq	31.39	clayey sand	sand	4341	3385	1.282
165	CB3-BOR	Florida	PSC24"sq	23.47	clayey sand	sand	2224	2509	0.886
166	CB3-BORL	Florida	PSC24"sq	23.71	clayey sand	sand	2224	2233	0.996
167	CB5-BOR	Florida	VC 30"sq	16.18	clayey sand	sand	5560	2527	2.200
168	CB5-BORL	Florida	VC 30"sq	16.46	clayey sand	sandy clay	5560	2598	2.140
169	CBI 1-BORL	Florida	VC 30"sq	26.12	clayey sand	clayey sand	6383	3621	1.763
170	CB11-EORL	Florida	VC 30"sq	26.15	clayey sand	clayey sand	6383	2842	2.246
171	CB17-BOR1	Florida	VC 30"sq	23.68	clayey sand	clayey sand	6739	3648	1.847
172	CB17-BOR2	Florida	VC 30"sq	23.71	clayey sand	clayey sand	6739	3332	2.023
173	CB17-BORL	Florida	VC 30"sq	23.74	clayey sand	clayey sand	6739	3038	2.218
174	CB17-DRL	Florida	VC 30"sq	23.84	clayey sand	clayey sand	6739	3759	1.793
175	CB23-BOR	Florida	VC 30"sq	24.48	clayey sand	sand	2860	2753	1.039
176	CB23-BORE	Florida	VC30"sq	25.21	clayey sand	sand	2860	1975	1.448
177	CB29-BORL	Florida	VC 30"sq	25.76	clayey sand	clayey sand	4079	3452	1.182
178	CB29-EORL	Florida	VC 30"sq	25.76	clayey sand	clayey sand	4079	1997	2.043
179	CB35-BOR1	Florida	VC 30"sq	23.93	clayey sand	clayey sand	6508	3612	1.802
180	CB35-BOR2	Florida	VC 30"sq	24.05	clayey sand	clayey sand	6508	4221	1.542
181	CB35-BORL	Florida	VC 30"sq	24.11	clayey sand	clayey sand	6508	4043	1.610
182	CB41-EOR	Florida	VC 30"sq	19.72	sandy clay	sandy clay	6272	3812	1.645
183	CB41-BOR	Florida	VC 30"sq	19.72	sandy clay	sandy clay	6272	3781	1.659
184	CB41-BORL	Florida	VC 30"sq	19.93	sandy clay	sandy clay	6272	2157	2.908
185	CB26-EOD	Florida	PSC24"sq	19.05	clayey sand	sand	4270	2171	1.967
186	CB26-BOR	Florida	PSC24"sq	19.08	clayey sand	sand	4270	2753	1.551
187	CB26-EOR	Florida	PSC24"sq	19.75	clayey sand	sandy clay	4270	3185	1.341
188	CB26-BOR2	Florida	PSC24"sq	19.81	sandy clay	sandy clay	4270	2504	1.705
235	PO2-BOR1	Florida	PSC18"sq	5.73	sand	dense sand	1219	1352	0.902
236	PO2-BOR2	Florida	PSC18"sq	6.07	sand	dense sand	1219	1174	1.038
237	PO2-BORL	Florida	PSC18"sq	6.28	sand	dense sand	1219	1250	0.975
238	PO19-BOR	Florida	PSC18"sq	4.63	sand	dense sand	1023	1334	0.767
239	PO19-EOD	Florida	PSC18"sq	5.24	sand	dense sand	1023	1090	0.939
240	PO19-EORL	Florida	PSC18"sq	5.36	sand	dense sand	1023	1045	0.979
241	ER5-BOR1	Florida	PSC24"sq	25.97	sand	sand	3803	2927	1.299
242	ER5-BOR2	Florida	PSC24"sq	26.03	sand	sand	3803	4123	0.922
243	ER5-BORL	Florida	PSC24"sq	26.15	sand	sand	3803	2611	1.457
244	ER77-BOR	Florida	PSC24"sq	18.56	clayey sand	cl-si-sand	7433	3363	2.210
245	ER77-BORL	Florida	PSC24"sq	18.68	clayey sand	cl-si-sand	7433	4484	1.658
246	BB13-EOD	Florida	VC 30"sq	28.29	clayey sand	sand	4475	3114	1.437
247	BB13-BOR1a	Florida	VC 30"sq	28.32	clayey sand	sand	4475	4092	1.094
248	BB13-BORIb	Florida	VC 30"sq	28.32	clayey sand	sand	4475	3959	1.130
249	BB 13-BOR2a	Florida	VC 30"sq	28.71	clayey sand	sand	4475	4760	0.940
250	BB13-BOR2b	Florida	VC 30"sq	28.71	clayey sand	sand	4475	4671	0.958
251	BB I3-BORL	Florida	VC 30"sq	28.8	clayey sand	sand	4475	4008	1.117
252	BB19-BORa	Florida	VC 30"sq	27.13	sand	sand	5169	4155	1.244
253	BB19-BORb	Florida	VC 30"sq	27.13	sand	sand	5169	4666	1.108
254	BB19-BORL	Florida	VC 30"sq	27.19	sand	sand	5169	6512	0.794

Table C-5 (cont.)

255	BB24-EOD	Florida	VC 30"sq	24.44	sand	clay	4955	5783	0.857
256	BB24-BOR1a	Florida	VC 30"sq	24.48	sand	clay	4955	7517	0.659
257	BB24-BORIb	Florida	VC 30"sq	24.48	sand	clay	4955	7571	0.654
258	BB24-BOR2a	Florida	VC 30"sq	24.63	sand	clay	4955	8420	0.588
259	I31324-BOR2b	Florida	VC 30"sq	24.63	sand	clay	4955	7873	0.629
260	BB24-BORL	Florida	VC 30"sq	24.69	sand	clay	4955	6241	0.794
261	BB29-BOR	Florida	VC 30"sq	23.90 -	sand	sand	5053	5458	0.926
262	BB29-BORL	Florida	VC 30"sq	23.96	sand	sand	5053	5115	0.988
263	ABF6-BOR	Florida	PSC 24" sq	17.54	si/clayey sand	clayey sand	3345	1677	1.995
264	ABF6-BORL	Florida	PSC 24" sq	17.84	si/clayey sand	clayey sand	3345	3474	0.963
265	ABG13-BORL	Florida	PSC 24" sq	14.08	clayey sand	limestone	4742	4826	0.983
266	ABH2-BOR	Florida	PSC 24" sq	10.9	silt/silty clay	limestone	2518	3594	0.701
267	ABH2-BORL	Florida	PSC 24" sq	10.96	silt/silty clay	limestone	2518	4092	0.615
286	DD22-EOD	Florida	PSC 14"sq	27.43	clay	sand	3745	1134	3.302
287	DD22-BOR	Florida	PSC 14"sq	27.74	clay	sand	3745	2309	1.622
288	DD23-EOD	Florida	CEP 12.75	24.99	clay	sand	2206	681	3.239
289	DD23-BOR	Florida	CEP 12.75	25.09	clay	sand	2206	1232	1.791
328	DD29-EOD	Florida	CEP 12.75"	49.68	clayey sand	clayey sand	NA	1561	
375	UFSSIA - BOR	Florida	PSC 24" sq	15	cl-si-sand	silty clay	3496	5427	0.644
376	UFSSIB - BOR	Florida	PSC 20" sq	14.42	cl-si-sand	silty clay	2611	3554	0.735
377	UFSS I O - BOR	Florida	PSC 24" sq	8.5	sa-si-clay	silty clay	5107	6228	0.820
378	UFSS13B - BOR	Florida	PSC 24" sq	8.2	sa-si-clay	silty clay	2771	4226	0.656
379	BIT20 - BOR	Florida	PSC 20" sq	14.08	Silty sand	sand	2593	2108	1.230
380	BIT21 - BOR	Florida	PSC 20" sq	11.09	cl-si-sand	silty sand	1637	1606	1.019
381	HFLS3 - EOD	Florida	PSC 30" sq	12.07	sa-si-clay	sandy clay	7073	5787	1.222
382	HFLS4L - EOD	Florida	PSC 30" sq	22.4	cl-si-limestone-sand	limerock	3354	3136	1.070
383	HFLS4L - BOR	Florida	PSC 30" sq	22.4	cl-si-limestone-sand	limerock	3354	4070	0.824
384	RBA30 - BOR	Florida	PSC 30" sq	16.28	Silty sand	silty sand	4039	3692	1.094
385	RBB30W - BOR	Florida	PSC 30" sq	13.35	Silty sand	silty sand	3461	3225	1.073
386	CC6 - BOR	Florida	PSC 18" sq	16.18	Silty sand	sand	1388	1423	0.975
387	CC7 - BOR	Florida	PSC 14" sq	23.23	cl-si-sand	silty sand	1770	1810	0.978
388	CC14 - BOR	Florida	PSC 14" sq	21.18	cl-si-sand	silty sand	1601	1890	0.847
389	49SB37 - EOD	Florida	PSC 30" sq	7.13	sandy clay	silty limestone	5058	4559	1.109

N		**107**
Average		**1.324**
SD		**0.571**
COV		**0.431**
Φ	**β=2.33**	**0.564**
	β=3.0	**0.412**

Table C-6 Louisiana CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
65	FL3-EOD	Louisiana	PSC24"sq	25.69	silty clay	silty sand	1779	605	2.940
66	FL3-BOR	Louisiana	PSC24"sq	25.69	silty clay	silty sand	1779	1210	1.470
67	FL3-BOR2	Louisiana	PSC24"sq	25.69	silty clay	silty sand	1779	1557	1.143
291	LB3-EOD	Kenner, LA	PSC 24" sq	24.84	clay	Sand	1842	269	6.848
292	LB3-BOR1	Kenner, LA	PSC 24" sq	24.99	clay	Sand	1842	912	2.020
293	LB3-BOR2	Kenner, LA	PSC 24" sq	24.99	clay	Sand	1842	1534	1.201
294	LB3-BOR3	Kenner, LA	PSC 24" sq	24.99	clay	Sand	1842	1677	1.098
295	LB4-EOD	Kenner, LA	PSC 30" sq	24.99	clay	Sand	2273	202	11.252
296	LB4-BOR1	Kenner, LA	PSC 30" sq	25.21	clay	Sand	2273	887	2.563
297	LB4-BOR2	Kenner, LA	PSC 30" sq	25.27	clay	Sand	2273	1299	1.750
298	LB4-BOR3	Kenner, LA	PSC 30" sq	25.3	clay	Sand	2273	1521	1.494
299	LB4-BOR4	Kenner, LA	PSC 30" sq	25.3	clay	Sand	2273	1603	1.418
300	LB5-EOD	Kenner, LA	PSC 30" sq	24.99	clay	Sand	NA	263	
301	LB5-BOR1	Kenner, LA	PSC 30" sq	24.99	clay	Sand	NA	952	
302	LB5-BOR2	Kenner, LA	PSC 30" sq	24.99	clay	Sand	NA	1402	
303	LB5-BOR3	Kenner, LA	PSC 30" sq	25.3	clay	Sand	NA	1591	
304	LB5-BOR4	Kenner, LA	PSC 30" sq	25.3	clay	Sand	NA	1752	
305	LB6-EOD	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2411	404	5.968
306	LB6-BOR1	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2411	883	2.730
307	LB6-BOR2	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2411	1322	1.824
308	LB6-BOR3	Kenner, LA	PSC 36" cyl	24.99	clay	Sand	2411	1767	1.364
309	LB6-BOR4	Kenner, LA	PSC 36" cyl	24.99	clay	Sand	2411	2300	1.048
310	LB7-EOD	Kenner, LA	PSC 36" cyl	24.6	clay	Sand	2402	457	5.256
311	LB7-BOR1	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	875	2.745
312	LB7-BOR2	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	1279	1.878
313	LB7-BOR3	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	1891	1.270
314	LB7-BOR4	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	2260	1.063
								N	**22**
								Average	**2.743**
								SD	**2.509**
								COV	**0.912**
								Φ **β=2.33**	**0.425**
								β=3.0	**0.247**

Table C-7 Massachusetts CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
115	GZZ5-EOD	Boston MA	CEP 14"	26.52	till-clay	till	2064	952	2.168
116	GZO5-EOD	Boston MA	CEP 14"	16.46	till-clay	till	2135	912	2.341
117	GZCC5-EOD	Boston MA	CEP 14"	24.38	till-clay	till	2002	2189	0.915
118	GZL2-EOD	Boston MA	CEP 14"	25.3	till-clay	till	2847	1188	2.396
119	GZP14-EOD	Boston MA	CEP 14"	18.44	till-clay	till	1735	1357	1.279

Table C-7 (cont.)

120	GZP11-EOD	Boston MA	CEP 14"	17.22	till-clay	till	1112	1063	1.046
121	GZP12-EOD	Boston MA	CEP 14"	21.03	till-clay	till	2224	2313	0.962
315	DI221-EOD	Massachusetts	PSC 14" sq	19.2	sa-si-clay	fine sand & silt	1477		
316	DI221-BOR	Massachusetts	PSC 14" sq	19.2	sa-si-clay	fine sand & silt	1477	1250	1.182
317	TW488-EOD	Massachusetts	PSC 14" sq	23.16	stiff clay	stiff clay	1423	365	3.899
318	TW488-BOR	Massachusetts	PSC 14" sq	23.16	stiff clay	stiff clay	1423	934	1.524
319	NBTP2-EOD	Massachusetts	HP12X74	34.14	si-sa-clay	glacial till	1806	1352	1.336
320	NBTP2-BOR	Massachusetts	HP12X74	34.14	si-sa-clay	glacial till	1806	1601	1.128
321	NBTP2-BOR	Massachusetts	HP12X74	34.14	si-sa-clay	glacial till	1806	1686	1.071
322	NBTP3-EOD	Massachusetts	HP12X74	33.07	si-sa-clay	silty	2126	1401	1.517
323	NBTP3-BOR	Massachusetts	HP12X74	33.07	si-sa-clay	silty	2126	1601	1.328
324	NBTP3-BOR	Massachusetts	HP12X74	33.07	si-sa-clay	silty	2126	1713	1.241
325	NBTP5-EOD	Massachusetts	CEP12.75"	33.83	si-sa-clay	glacial till	1632	1423	1.147
326	NBTP5-BOR	Massachusetts	CEP12.75"	33.83	si-sa-clay	glacial till	1632	2046	0.798
								N	**17**
								Average	**1.515**
								SD	**0.758**
								COV	**0.500**
								Φ **β=2.33**	**0.555**
								β=3.0	**0.392**

Table C-8 Nebraska CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
1	FN1-EOD	Omaha NE	HP1Ox42	21.95	silty clay	till	1352	1023	1.322
2	FNI-BOR1	Omaha NE	HPIOx42	21.98	silty clay	till	1352	1668	0.811
3	FN1-BOR2	Omaha NE	HPIOx42	22.25	silty clay	till	1352	1917	0.705
4	FN2-EOD	Omaha NE	PSC12"sq	19.81	silty clay	till	1592	1005	1.584
5	FN2-BOR	Omaha NE	PSC12"sq	19.81	silty clay	till	1592	1357	1.173
6	FN3-EOD	Omaha NE	PSC14"sq	17.07	silty clay	till	1681	796	2.112
7	FN3-BOR	Omaha NE	PSC14"sq	17.07	silty clay	till	1681	1321	1.273
8	FN4-EOD	Omaha NE	CEP12.75"	20.12	silty clay	till	1263	1085	1.164
9	FN4-BOR	Omaha NE	CEP12.75"	20.12	silty clay	till	1263	1281	0.986
								N	**9**
								Average	**1.237**
								SD	**0.423**
								COV	**0.342**
								Φ **β=2.33**	**0.638**
								β=3.0	**0.489**

Table C-9 Oklahoma CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
14	FOl-EOD	Oklahoma	CEP 26"	18.35	silty sand	silty sand	2660	2206	1.206
15	FO1-BOR	Oklahoma	CEP 26"	18.35	silty sand	silty sand	2660	3114	0.854
16	FO2-EOD	Oklahoma	PSC24"oct	19.2	silty sand	silty sand	3381	2358	1.434
17	FO2-BOR	Oklahoma	PSC24"oct	19.23	silty sand	silty sand	3381	3252	1.040
18	FO3-EOD	Oklahoma	HP14x117	19.42	sa-si-clay	clayey sand	3452	2518	1.371
19	FO4-EOD	Oklahoma	RC24"sq	13.72	sa-si-clay	clayey sand	7562	2927	2.584
20	F04-BOR	Oklahoma	RC24"sq	17.01	sa-si-clay	clayey sand	7562	3412	2.216
								N	**7**
								Average	**1.529**
								SD	**0.635**
								COV	**0.415**
								Φ **β=2.33**	**0.675**
								β=3.0	**0.498**

Table C-10 Oklahoma CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
189	33P1-EOD	Ontario	HP 12x74	34.87	cl-sa-silt	silty sand	3559	1953	1.822
190	33P1-BOR	Ontario	HP 12x74	34.87	cl-sa-silt	silty sand	3559	3180	1.119
191	33P1-BOR	Ontario	HP 12x74	34.87	cl-sa-silt	silty sand	3559	2891	1.231
192	33P2-EOD	Ontario	CP 12.75"	32.67	cl-sa-silt	silty sand	2180	1290	1.690
193	33P2-BOR	Ontario	CP 12.75"	32.67	cl-sa-silt	silty sand	2180	1579	1.381
194	33P2-BOR	Ontario	CP 12.75"	32.67	cl-sa-silt	silty sand	2180	1784	1.222
195	33P4-EOD	Ontario	PSC 12"sq	16.52	cl-sa-silt	cl-silt-till	2073	1779	1.165
196	33P5-EOD	Ontario	#14 Timber	8.66	cl-sa-silt	cl-silt-till	730	636	1.148
197	TRD22-EOD	Ontario	HP 12x74	6.13	sand	till	1575	1922	0.819
198	TRD22-BOR	Ontario	HP 12x74	6.13	sand	till	1575	1308	1.204
199	TRE22-EOD	Ontario	HP 12x74	7.83	sand	rock	2473	2558	0.967
200	TRE22-BOR	Ontario	HP 12x74	7.83	sand	rock	2473	2740	0.903
201	TRP5X-EOD	Ontario	HP 12x53	7.68	sand	rock	1824	2153	0.847
202	TRP5X-BOR	Ontario	HP 12x53	7.68	sand	rock	1824	1757	1.038
203	TR131-BOR	Ontario	CP 7.063"	NA	sand	rock	623	738	0.844
								N	**15**
								Average	**1.160**
								SD	**0.294**
								COV	**0.254**
								Φ **β=2.33**	**0.715**
								β=3.0	**0.573**

Table C-11 Pennsylvania CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
61	FP5-EOD	Penn.	Monotube	7.19	sandy grvl	sandy grvl	1081	934	1.157
62	FP5-BOR	Penn.	Monotube	7.25	sandy grvl	sandy grvl	1081	1063	1.017
98	63S-BOR	Penn.	HP12x53	20.12	sand-silt	silt	1263	1241	1.018
128	GF19-EOD	Pgh. PA	HP1Ox42	15.09	grvl-snd-slt	shale	1468	1770	0.829
129	GF110-EOD	Pgh. PA	HP12x74	15.15	grvl-snd-slt	shale	2224	2033	1.094
130	GF222-EOD	Pgh. PA	HP12x74	18.62	grvl-snd-slt	shale	2580	2277	1.133
131	GF224-EOD	Pgh. PA	Monotube	9.02	grvl-snd-slt	grvl-snd-slt	NA	1864	
132	GF312-EOD	Pgh. PA	HP12x74	8.6	snd-grvl-shl	shale	1512	1802	0.839
133	GF313-EOD	Pgh. PA	HP10x57	9.6	snd-grvl-shl	claystone	1486	1984	0.749
134	GF412-EOD	Pgh. PA	HP12x74	10.24	grvl-snd-slt	claystone	1068	2024	0.528
135	GF413-EOD	Pgh. PA	HP10x57	10.55	grvl-snd-slt	claystone	1334	1904	0.701
136	GF414-EOD	Pgh. PA	HPIOx57	10.58	grvl-snd-slt	claystone	1601	2331	0.687
137	GF415-EOD	Pgh. PA	HP12x74	10.39	grvl-snd-slt	claystone	2046	2495	0.820
								N	**12**
								Average	**0.881**
								SD	**0.201**
								COV	**0.228**
								Φ **β=2.33**	**0.570**
								β=3.0	**0.462**

Table C-12 Wisconsin CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
207	CHAT-EOD	Wisconsin	CEP 12.75"	37.49	sa-si clay	silty sand	2909	1735	1.677
208	CHAT-BOR1	Wisconsin	CEP 12.75"	37.52	sa-si clay	silty sand	2909	2068	1.407
209	CHA1-BOR2	Wisconsin	CEP 12.75"	37.52	sa-si clay	silty sand	2909	2304	1.263
210	CHA4-EOD	Wisconsin	CEP 12.75"	35.66	sa-si clay	silty sand	2251	1205	1.868
211	CHB2-EOD	Wisconsin	HP12x63	47.34	sa-si clay	silty sand	1343	489	2.746
212	CHB2-BOR1	Wisconsin	HP12x63	47.34	sa-si clay	silty sand	1343	1201	1.118
213	CHB2-BOR3	Wisconsin	HP12x63	47.4	sa-si clay	silty sand	1343	1512	0.888
214	CHB2-BOR4	Wisconsin	HP12x63	47.43	sa-si clay	silty sand	1343	2002	0.671
215	CHB2-BOR5a	Wisconsin	HP12x63	47.46	sa-si clay	silty sand	1343	2291	0.586
216	CHB2-BOR5b	Wisconsin	HP12x63	47.46	sa-si clay	silty sand	1343	2126	0.632
217	CHB3-EOD	Wisconsin	HP12x63	43.31	sa-si clay	silty sand	890	467	1.906
218	CHB3-BOR1	Wisconsin	HP12x63	43.31	sa-si clay	silty sand	890	1045	0.852
219	CHB3-BOR2	Wisconsin	HP12x63	43.43	sa-si clay	silty sand	890	979	0.909
220	CHB3-BOR3	Wisconsin	HP12x63	43.53	sa-si clay	silty sand	890	1490	0.597
221	CHC3-EOD	Wisconsin	CEP14"	47.3	sa-si clay	silty sand	836	489	1.710
222	CHC3-BOR	Wisconsin	CEP14"	47.3	sa-si clay	silty sand	836		
223	CHC3-BORL	Wisconsin	CEP14"	47.34	sa-si clay	silty sand	836	1735	0.482
224	CH4-EOD	Wisconsin	CEP9.63"	43.43	silty clay		1601	667	2.400
225	CH4-BOR	Wisconsin	CEP9.63"	43.43	silty clay		1601	1512	1.059
226	CH39-EOD	Wisconsin	CEP9.63"	43.28	silty clay	silty clay	2936	832	3.529

Table C12 (cont.)

227	CH39-BOR	Wisconsin	CEP9.63	43.28	silty clay	silty clay	2936	2046	1.435
228	CH39-BORL	Wisconsin	CEP9.63"	43.37	silty clay	silty clay	2936	2558	1.148
229	CH6-5B-EOD	Wisconsin	CEP9.63"	43.89	silty clay	silty sand	1673		
230	CH6-5B-BOR	Wisconsin	CEP9.63"	43.89	silty clay	silty sand	1673	1779	0.940
231	CH95B-EOD	Wisconsin	CEP9.63"	42.37	silty clay	sand & grvl	2473	983	2.516
232	CH95B-BOR	Wisconsin	CEP9.63"	42.37	silty clay	sand & grvl	2473	2358	1.049
233	CH256-BOR3	Wisconsin	CEP9.63"	42.67	si-sa clay	si-sa & grvl	2651	2224	1.192
234	CH351-BOR2	Wisconsin	CEP9.63"	47.55	si-sa clay	si-sa & grvl	2669	2358	1.132
346	CHI1-42-BOR1	Wisconsin	CEP 12.75"	28.99	sa-cl-silt	silty clay	1948	2349	0.829
								N	**27**
								Average	**1.353**
								SD	**0.742**
								COV	**0.548**
								Φ **β=2.33**	**0.446**
								Φ **β=3.0**	**0.307**

Table C-13 Canada CAPWAP (EOD+BOR) Data

No	Pile-Case Number	Refer. No.	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
						Side	Tip			
91	35-1-BOR	C.N.R.	Toronto	HP12x74	14.78	cl-sa-silt	silty sand	1432	1157	1.238
92	35-4-BOR	C.N.R.	Toronto	CEP12.75"	14.69	cl-sa-silt	silty sand	1468	1601	0.917
93	35-5-BOR	C.N.R.	Toronto	HP12x74	27.58	cl-sa-silt	silty sand	2722	2891	0.942
94	35-6-BOR	C.N.R.	Toronto	CEP12.75"	27.43	cl-sa-silt	silty sand	2669	2580	1.034
95	35-7-BOR	C.N.R.	Toronto	T.Timber	12.68	cl-sa-silt	silty sand	543	618	0.879
96	35-10-BOR	C.N.R.	Toronto	PSC 12"sq	14.63	cl-sa-silt	silty sand	1788	1486	1.203
138	EF62-EOD	Ottawa	Canada	CP 9.625"	18.99	si-sa-clay	till	2233	2322	0.962
139	EF167-BOR	Ottawa	Canada	CP 9.625"	21	si-sa-clay	till	1205	2131	0.565
									N	**8**
									Average	**0.967**
									SD	**0.209**
									COV	**0.216**
									Φ **β=2.0**	**0.640**
									Φ **β=2.5**	**0.521**

Table C-14 Alabama CAPWAP (BOR) Data

No.	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
42	FA1-BOR1	Alabama	PSC 18"sq	19.66	silty sand	silty sand	1646	1143	1.440
43	FAI-BOR2	Alabama	PSC 18"sq	19.75	silty sand	silty sand	1646	1699	0.969
45	FA2-BORI	Alabama	PSC 18"sq	22.95	silty sand	silty sand	2447	2175	1.125
46	FA2-BOR2	Alabama	PSC 18"sq	23.01	silty sand	silty sand	2447	2664	0.919
48	FA3-BORI	Alabama	PSC 24"sq	19.54	silty sand	silty sand	2780	1366	2.035
49	FA3-BOR2	Alabama	PSC 24"sq	19.66	silty sand	silty sand	2780	2611	1.065
51	FA4-BOR1	Alabama	PSC 24"sq	22.89	silty sand	silty sand	3634	2687	1.352
52	FA4-BOR2	Alabama	PSC 24"sq	22.92	silty sand	silty sand	3634	3790	0.959
54	FA5-BOR	Alabama	PSC 36"sq	22.28	silty sand	silty sand	5071	4204	1.206
								N	**9**
								Average	**1.230**
								SD	**0.351**
								COV	**0.285**
								Φ **β=2.33**	**0.713**
								Φ **β=3.0**	**0.562**

Table C-15 Florida CAPWAP (BOR) Data

No.	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
79	WC3-BORI	Florida	PSC24"sq	8.38	Is.-d.sand	dense	2713	2251	1.205
80	WC3-BOR2	Florida	PSC24"sq	8.38	Is: d.sand	dense	2713	2384	1.138
82	WC6-BOR1	Florida	PSC24"sq	8.69	ls.-d.sand	dense	2015	2135	0.944
83	WC6-BOR2	Florida	PSC24"sq	8.38	Is.-d.sand	dense	2015	1971	1.022
84	WB9-BOR	Florida	PSC30"sq	39.17	clayey sand	clayey	4003	4186	0.956
85	WB15-BOR	Florida	PSC30"sq	31.58	sand	silt-clay	3648	3581	1.019
141	A3-BOR2	Florida	VC 24"sq	27.55	clayey sand	sand	4261	2055	2.073
142	A3-BOR3	Florida	VC 24"sq	27.61	clayey sand	clayey sand	4261	4115	1.035
145	A14-BOR1	Florida	VC 24"sq	17.83	clayey sand	sand		2687	
146	A14-BOR2	Florida	VC 24"sq	17.92	clayey sand	sand		4279	
148	A25-BOR1	Florida	VC 24"sq	16.82	clayey sand	sand	3180	2469	1.288
149	A25-BOR2	Florida	VC 24"sq	16.89	clayey sand	sand	3180	2011	1.581
150	A25-BOR3	Florida	VC 24"sq	16.92	clayey sand	sand	3180	1966	1.617
152	A16-BOR1	Florida	PSC18"sq	18.47	sandy clay	sand	1401	1254	1.117
153	A16-BOR2	Florida	PSC18"sq	18.59	sandy clay	sand	1401	1317	1.064
155	A41-BOR1	Florida	VC 24"sq	15.85	clay	sand	2331	2237	1.042
156	A41-BOR2	Florida	VC 24"sq	16.09	clay	sand	2331	2513	0.928
158	A101-BORI	Florida	VC 24"sq	18.84	clay	clayey sand	3612	2976	1.214
159	A101-BOR2	Florida	VC 24"sq	18.93	clay	clayey sand	3612	3572	1.011
161	A133-BOR	Florida	VC 24"sq	31.97	clayey sand	sandy clay	3594	3470	1.036
163	A145-BOR1	Florida	VC 24"sq	31.36	clayey sand	sand	4341	2851	1.523
164	A145-BOR2	Florida	VC 24"sq	31.39	clayey sand	sand	4341	3385	1.282
165	CB3-BOR	Florida	PSC24"sq	23.47	clayey sand	sand	2224	2509	0.886
166	CB3-BORL	Florida	PSC24"sq	23.71	clayey sand	sand	2224	2233	0.996

Table C-15 (cont.)

167	CB5-BOR	Florida	VC 30"sq	16.18	clayey sand	sand	5560	2527	2.200
168	CB5-BORL	Florida	VC 30"sq	16.46	clayey sand	sandy clay	5560	2598	2.140
169	CB11-BORL	Florida	VC 30"sq	26.12	clayey sand	clayey sand	6383	3621	1.763
170	CB11-EORL	Florida	VC 30"sq	26.15	clayey sand	clayey sand	6383	2842	2.246
171	CB17-BOR1	Florida	VC 30"sq	23.68	clayey sand	clayey sand	6739	3648	1.847
172	CB17-BOR2	Florida	VC 30"sq	23.71	clayey sand	clayey sand	6739	3332	2.023
173	CB17-BORL	Florida	VC 30"sq	23.74	clayey sand	clayey sand	6739	3038	2.218
174	CB17-DRL	Florida	VC 30"sq	23.84	clayey sand	clayey sand	6739	3759	1.793
175	CB23-BOR	Florida	VC 30"sq	24.48	clayey sand	sand	2860	2753	1.039
176	CB23-BORE	Florida	VC30"sq	25.21	clayey sand	sand	2860	1975	1.448
177	CB29-BORL	Florida	VC 30"sq	25.76	clayey sand	clayey sand	4079	3452	1.182
178	CB29-EORL	Florida	VC 30"sq	25.76	clayey sand	clayey sand	4079	1997	2.043
179	CB35-BOR1	Florida	VC 30"sq	23.93	clayey sand	clayey sand	6508	3612	1.802
180	CB35-BOR2	Florida	VC 30"sq	24.05	clayey sand	clayey sand	6508	4221	1.542
181	CB35-BORL	Florida	VC 30"sq	24.11	clayey sand	clayey sand	6508	4043	1.610
182	CB41-EOR	Florida	VC 30"sq	19.72	sandy clay	sandy clay	6272	3812	1.645
183	CB41-BOR	Florida	VC 30"sq	19.72	sandy clay	sandy clay	6272	3781	1.659
184	CB41-BORL	Florida	VC 30"sq	19.93	sandy clay	sandy clay	6272	2157	2.908
186	CB26-BOR	Florida	PSC24"sq	19.08	clayey sand	sand	4270	2753	1.551
187	CB26-EOR	Florida	PSC24"sq	19.75	clayey sand	sandy clay	4270	3185	1.341
188	CB26-BOR2	Florida	PSC24"sq	19.81	sandy clay	sandy clay	4270	2504	1.705
235	PO2-BOR1	Florida	PSC18"sq	5.73	sand	dense sand	1219	1352	0.902
236	PO2-BOR2	Florida	PSC18"sq	6.07	sand	dense sand	1219	1174	1.038
237	PO2-BORL	Florida	PSC18"sq	6.28	sand	dense sand	1219	1250	0.975
238	PO19-BOR	Florida	PSC18"sq	4.63	sand	dense sand	1023	1334	0.767
240	PO19-EORL	Florida	PSC18"sq	5.36	sand	dense sand	1023	1045	0.979
241	ER5-BOR1	Florida	PSC24"sq	25.97	sand	sand	3803	2927	1.299
242	ER5-BOR2	Florida	PSC24"sq	26.03	sand	sand	3803	4123	0.922
243	ER5-BORL	Florida	PSC24"sq	26.15	sand	sand	3803	2611	1.457
244	ER77-BOR	Florida	PSC24"sq	18.56	clayey sand	cl-si-sand	7433	3363	2.210
245	ER77-BORL	Florida	PSC24"sq	18.68	clayey sand	cl-si-sand	7433	4484	1.658
247	BB13-BOR1a	Florida	VC 30"sq	28.32	clayey sand	sand	4475	4092	1.094
248	BB13-BORIb	Florida	VC 30"sq	28.32	clayey sand	sand	4475	3959	1.130
249	BB 13-BOR2a	Florida	VC 30"sq	28.71	clayey sand	sand	4475	4760	0.940
250	BB13-BOR2b	Florida	VC 30"sq	28.71	clayey sand	sand	4475	4671	0.958
251	BB I3-BORL	Florida	VC 30"sq	28.8	clayey sand	sand	4475	4008	1.117
252	BB19-BORa	Florida	VC 30"sq	27.13	sand	sand	5169	4155	1.244
253	BB19-BORb	Florida	VC 30"sq	27.13	sand	sand	5169	4666	1.108
254	BB19-BORL	Florida	VC 30"sq	27.19	sand	sand	5169	6512	0.794
256	BB24-BOR1a	Florida	VC 30"sq	24.48	sand	clay	4955	7517	0.659
257	BB24-BORIb	Florida	VC 30"sq	24.48	sand	clay	4955	7571	0.654
258	BB24-BOR2a	Florida	VC 30"sq	24.63	sand	clay	4955	8420	0.588
259	I31324-BOR2b	Florida	VC 30"sq	24.63	sand	clay	4955	7873	0.629
260	BB24-BORL	Florida	VC 30"sq	24.69	sand	clay	4955	6241	0.794
261	BB29-BOR	Florida	VC 30"sq	23.90 -	sand	sand	5053	5458	0.926
262	BB29-BORL	Florida	VC 30"sq	23.96	sand	sand	5053	5115	0.988

Table C-15 (cont.)

263	ABF6-BOR	Florida	PSC 24" sq	17.54	si/clayey sand	clayey sand	3345	1677	1.995
264	ABF6-BORL	Florida	PSC 24" sq	17.84	si/clayey sand	clayey sand	3345	3474	0.963
265	ABG13-BORL	Florida	PSC 24" sq	14.08	clayey sand	limestone	4742	4826	0.983
266	ABH2-BOR	Florida	PSC 24" sq	10.9	silt/silty clay	limestone	2518	3594	0.701
267	ABH2-BORL	Florida	PSC 24" sq	10.96	silt/silty clay	limestone	2518	4092	0.615
375	UFSSIA - BOR	Florida	PSC 24" sq	15	cl-si-sand	silty clay	3496	5427	0.644
376	UFSSIB - BOR	Florida	PSC 20" sq	14.42	cl-si-sand	silty clay	2611	3554	0.735
377	UFSS I O - BOR	Florida	PSC 24" sq	8.5	sa-si-clay	silty clay	5107	6228	0.820
378	UFSS13B - BOR	Florida	PSC 24" sq	8.2	sa-si-clay	silty clay	2771	4226	0.656
379	BIT20 - BOR	Florida	PSC 20" sq	14.08	silty sand	sand	2593	2108	1.230
380	BIT21 - BOR	Florida	PSC 20" sq	11.09	cl-si-sand	silty sand	1637	1606	1.019
383	HFLS4L - BOR	Florida	PSC 30" sq	22.4	cl-si-limestone-sand	limerock	3354	4070	0.824
384	RBA30 - BOR	Florida	PSC 30" sq	16.28	silty sand	silty sand	4039	3692	1.094
385	RBB30W - BOR	Florida	PSC 30" sq	13.35	silty sand	silty sand	3461	3225	1.073
386	CC6 - BOR	Florida	PSC 18" sq	16.18	silty sand	sand	1388	1423	0.975
387	CC7 - BOR	Florida	PSC 14" sq	23.23	cl-si-sand	silty sand	1770	1810	0.978
388	CC14 - BOR	Florida	PSC 14" sq	21.18	cl-si-sand	silty sand	1601	1890	0.847
								N	**85**
								Average	**1.243**
								SD	**0.475**
								COV	**0.382**
								Φ β=2.33	**0.589**
								β=3.0	**0.442**

Table C-16 Kenner, LA CAPWAP (BOR) Data

No.	Pile-Case Number	Location	Pile Type	Penetr Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
292	LB3-BOR1	Kenner, LA	PSC 24" sq	24.99	clay	Sand	1842	912	2.020
293	LB3-BOR2	Kenner, LA	PSC 24" sq	24.99	clay	Sand	1842	1534	1.201
294	LB3-BOR3	Kenner, LA	PSC 24" sq	24.99	clay	Sand	1842	1677	1.098
296	LB4-BOR1	Kenner, LA	PSC 30" sq	25.21	clay	Sand	2273	887	2.563
297	LB4-BOR2	Kenner, LA	PSC 30" sq	25.27	clay	Sand	2273	1299	1.750
298	LB4-BOR3	Kenner, LA	PSC 30" sq	25.3	clay	Sand	2273	1521	1.494
299	LB4-BOR4	Kenner, LA	PSC 30" sq	25.3	clay	Sand	2273	1603	1.418
301	LB5-BOR1	Kenner, LA	PSC 30" sq	24.99	clay	Sand		952	
302	LB5-BOR2	Kenner, LA	PSC 30" sq	24.99	clay	Sand		1402	
303	LB5-BOR3	Kenner, LA	PSC 30" sq	25.3	clay	Sand		1591	
304	LB5-BOR4	Kenner, LA	PSC 30" sq	25.3	clay	Sand		1752	
306	LB6-BOR1	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2411	883	2.730
307	LB6-BOR2	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2411	1322	1.824
308	LB6-BOR3	Kenner, LA	PSC 36" cyl	24.99	clay	Sand	2411	1767	1.364
309	LB6-BOR4	Kenner, LA	PSC 36" cyl	24.99	clay	Sand	2411	2300	1.048
311	LB7-BOR1	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	875	2.745

Table C-16 (cont.)

312	LB7-BOR2	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	1279	1.878
313	LB7-BOR3	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	1891	1.270
314	LB7-BOR4	Kenner, LA	PSC 36" cyl	24.69	clay	Sand	2402	2260	1.063
								N	**15**
								Average	**1.698**
								SD	**0.592**
								COV	**0.349**
								Φ **β=2.33**	**0.863**
								β=3.0	**0.659**

Table C-17 Ontario CAPWAP (BOR) Data

No.	Pile-Case Number	Refer. No.	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
						Side	Tip			
190	33P1-BOR	Site P	Ontario	HP 12x74	34.87	cl-sa-silt	silty sand	3559	3180	1.119
191	33P1-EOR	Site P	Ontario	HP 12x74	34.87	cl-sa-silt	silty sand	3559	2891	1.231
193	33P2-BOR	Site P	Ontario	CP 12.75"	32.67	cl-sa-silt	silty sand	2180	1579	1.381
194	33P2-EOR	Site P	Ontario	CP 12.75"	32.67	cl-sa-silt	silty sand	2180	1784	1.222
198	TRD22-BOR	Site R	Ontario	HP 12x74	6.13	sand	till	1575	1308	1.204
200	TRE22-BOR	Site R	Ontario	HP 12x74	7.83	sand	rock	2473	2740	0.903
202	TRP5X-BOR	Site R	Ontario	HP 12x53	7.68	sand	rock	1824	1757	1.038
203	TR131-BOR	Site R	Ontario	CP 7.063"	NA	sand	rock	623	738	0.844
									N	**8**
									Average	**1.118**
									SD	**0.180**
									COV	**0.161**
									Φ **β=2.33**	**0.809**
									β=3.0	**0.675**

Table C-18 S.Carolina CAPWAP (BOR) Data

No	Pile-Case Number	Location	Pile Type	Penetr Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
269	BC79-BORL	S.Carolina	PSC 24" oct	23.5	si-cl-sand	calcar sand	2277	2447	0.931
271	BC64-BORL	S.Carolina	PSC 24" oct	18.62	si-cl-sand	calcar sand	5071	5004	1.013
279	MB1-BOR	S. Carolina	PSC 16"sq	19.2	sand	silty sand	3590	2326	1.543
280	MB2-BOR	S. Carolina	HP14x89	20.12	silty sand	calcar. silt	3990	2362	1.689
281	MB3-BOR	S. Carolina	OEP 16"	20.12	silty sand	calcar. silt	4146	2540	1.632
283	SI-BOR	S. Carolina	OEP 24"	24.84	clayey sand	sandy silt	2651	2687	0.987
285	S2-BOR	S. Carolina	HP14x73	23.77	clayey sand	sandy silt	1415	1366	1.036
331	DWI-BOR1	S. Carolina	PSC 24" sq	27.46	silty clay	silty clay	4742	4515	1.050
332	DW 1-BOR2	S. Carolina	PSC 24" sq	27.52	silty clay	silty clay	4742	5178	0.916
333	DW2-BORI	S. Carolina	HP14X73	27.46	si-sa-clay	silty clay	2753	2798	0.984
334	DW2-BOR2	S. Carolina	HP14X73	27.52	si-sa-clay	silty clay	2753	3025	0.910

Table C-18 (cont.)

335	DS1-BORI	S. Carolina	PSC 12" sq	26.82	cl-si-sand	calcar sand	1601	1214	1.319
336	DS1-BOR2	S. Carolina	PSC 12" sq	26.85	cl-si-sand	calcar sand	1601	1535	1.043
								N	**13**
								Average	**1.158**
								SD	**0.285**
								COV	**0.246**
								Φ **β=2.33**	**0.703**
								β=3.0	**0.565**

Table C-19 Wisconsin CAPWAP (BOR) Data

No.	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
208	CHAT-BOR1	Wisconsin	CEP 12.75"	37.52	sa-si clay	silty sand	2909	2068	1.407
209	CHA1-BOR2	Wisconsin	CEP 12.75"	37.52	sa-si clay	silty sand	2909	2304	1.263
212	CHB2-BOR1	Wisconsin	HP12x63	47.34	sa-si clay	silty sand	1343	1201	1.118
213	CHB2-BOR3	Wisconsin	HP12x63	47.4	sa-si clay	silty sand	1343	1512	0.888
214	CHB2-BOR4	Wisconsin	HP12x63	47.43	sa-si clay	silty sand	1343	2002	0.671
215	CHB2-BOR5a	Wisconsin	HP12x63	47.46	sa-si clay	silty sand	1343	2291	0.586
216	CHB2-BOR5b	Wisconsin	HP12x63	47.46	sa-si clay	silty sand	1343	2126	0.632
218	CHB3-BOR1	Wisconsin	HP12x63	43.31	sa-si clay	silty sand	890	1045	0.852
219	CHB3-BOR2	Wisconsin	HP12x63	43.43	sa-si clay	silty sand	890	979	0.909
220	CHB3-BOR3	Wisconsin	HP12x63	43.53	sa-si clay	silty sand	890	1490	0.597
222	CHC3-BOR	Wisconsin	CEP14"	47.3	sa-si clay	silty sand	836		
223	CHC3-BORL	Wisconsin	CEP14"	47.34	sa-si clay	silty sand	836	1735	0.482
225	CH4-BOR	Wisconsin	CEP9.63"	43.43	silty clay		1601	1512	1.059
227	CH39-BOR	Wisconsin	CEP9.63	43.28	silty clay	silty clay	2936	2046	1.435
228	CH39-BORL	Wisconsin	CEP9.63"	43.37	silty clay	silty clay	2936	2558	1.148
230	CH6-5B-BOR	Wisconsin	CEP9.63"	43.89	silty clay	silty sand	1673	1779	0.940
232	CH95B-BOR	Wisconsin	CEP9.63"	42.37	silty clay	sand & grvl	2473	2358	1.049
233	CH256-BOR3	Wisconsin	CEP9.63"	42.67	si-sa clay	si-sa & grvl	2651	2224	1.192
234	CH351-BOR2	Wisconsin	CEP9.63"	47.55	si-sa clay	si-sa & grvl	2669	2358	1.132
								N	**18**
								Average	**0.964**
								SD	**0.286**
								COV	**0.296**
								Φ **β=2.33**	**0.547**
								β=3.0	**0.429**

Table C-20 Florida CAPWAP (EOD) Data

No.	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
78	WC3-EOD	Florida	PSC24"sq	8.32	Is.-d.sand	dense	2713	2264	1.198
81	WC6-EOD	Florida	PSC24"sq	8.63	Is.-dsand	dense	2015	2002	1.006
105	ST1-EOD	Florida	PSC 18"sq	13.41		carb sand	1530	2246	0.681

Table C-20 (cont.)

106	ST2-EOD	Florida	PSC 18"sq	12.19		carb sand	2269	2740	0.828
140	A3-EOD2	Florida	VC 24"sq	27.52	clayey sand	sand	4261	1637	2.603
147	A25-EOD	Florida	VC 24"sq	16.79	clayey sand	sand	3180	2042	1.557
151	AI6-EOD	Florida	PSC18"sq	18.47	sandy clay	sand	1401	996	1.407
154	A41-EOD	Florida	VC 24"sq	15.85	clay	sand	2331	1917	1.216
157	A101-EOD	Florida	VC 24"sq	18.84	clay	clayey sand	3612	2300	1.570
160	A133-EOD	Florida	VC 24"sq	31.67	clayey sand	sandy clay	3594	1383	2.599
162	A145-EOD	Florida	VC 24"sq	31.36	clayey sand	sand	4341	1570	2.765
185	CB26-EOD	Florida	PSC24"sq	19.05	clayey sand	sand	4270	2171	1.967
239	PO19-EOD	Florida	PSC18"sq	5.24	sand	dense sand	1023	1090	0.939
246	BB13-EOD	Florida	VC 30"sq	28.29	clayey sand	sand	4475	3114	1.437
255	BB24-EOD	Florida	VC 30"sq	24.44	sand	clay	4955	5783	0.857
381	HFLS3 - EOD	Florida	PSC 30" sq	12.07	sa-si-clay	sandy clay	7073	5787	1.222
382	HFLS4L - EOD	Florida	PSC 30" sq	22.4	cl-si-limestone-sand	limerock	3354	3136	1.070
389	49SB37 - EOD	Florida	PSC 30" sq	7.13	sandy clay	Silty limestone	5058	4559	1.109

	N	**18**
	Average	**1.503**
	SD	**0.650**
	COV	**0.433**
Φ	**β=2.33**	**0.638**
	β=3.0	**0.467**

Table C-21 Massachusetts CAPWAP(EOD) Data

No.	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
115	GZZ5-EOD	Boston MA	CEP 14"	26.52	till-clay	till	2064	952	2.168
116	GZO5-EOD	Boston MA	CEP 14"	16.46	till-clay	till	2135	912	2.341
117	GZCC5-EOD	Boston MA	CEP 14"	24.38	till-clay	till	2002	2189	0.915
118	GZL2-EOD	Boston MA	CEP 14"	25.3	till-clay	till	2847	1188	2.396
119	GZP14-EOD	Boston MA	CEP 14"	18.44	till-clay	till	1735	1357	1.279
120	GZP11-EOD	Boston MA	CEP 14"	17.22	till-clay	till	1112	1063	1.046
121	GZP12-EOD	Boston MA	CEP 14"	21.03	till-clay	till	2224	2313	0.962
315	DI221-EOD	Massachusetts	PSC 14"	19.2	sa-si-clay	fine sand & silt	1477		
317	TW488-EOD	Massachusetts	PSC 14"	23.16	stiff clay	stiff clay	1423	365	3.899
319	NBTP2-EOD	Massachusetts	HP12X74	34.14	si-sa-clay	glacial till	1806	1352	1.336
322	NBTP3-EOD	Massachusetts	HP12X74	33.07	si-sa-clay	silty	2126	1401	1.517
325	NBTP5-EOD	Massachusetts	CEP12.75"	33.83	si-sa-clay	glacial till	1632	1423	1.147

	N	**11**
	Average	**1.728**
	SD	**0.904**
	COV	**0.523**
Φ	**β=2.33**	**0.602**
	β=3.0	**0.419**

Table C-22 Oakland, CA CAPWAP (EOD) Data

No.	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
356	OD1J-EOD	Oakland, CA	OEP 24"	8.47	silty sand	silty clayey sand	7722	3496	2.209
357	OD2P-EOD	Oakland, CA	OEP 24"	12.19	silty sand	silty sandy clay	3047	1557	1.957
359	OD2T-EOD	Oakland, CA	CEP 24"	10.67	silty sand	silty sand & clay	3616	3634	0.995
360	OD3H-EOD	Oakland, CA	OEP 42"	30.63	stiff clay	clay w/ sa-si-gr	4639	1441	3.219
361	OD4L-EOD	Oakland, CA	CEP 24"	19.51	sandy clay	silty sandy clay	4399	2242	1.962
362	OD4P-EOD	Oakland, CA	CEP 24"	17.07	silty clay	silty sandy clay	3087	1214	2.543
364	OD4T-EOD	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3229	1339	2.412
366	OD4W-EOD	Oakland, CA	CEP 24"	18.29	sandy clay	silty sandy clay	3937	1766	2.229
								N	**8**
								Average	**2.191**
								SD	**0.629**
								COV	**0.287**
								Φ **β=2.33**	**1.265**
								Φ **β=3.0**	**0.997**

Table C-23 Ontario CAPWAP (EOD) Data

No.	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
189	33P1-EOD	Ontario	HP 12x74	34.87	cl-sa-silt	silty sand	3559	1953	1.822
192	33P2-EOD	Ontario	CP 12.75"	32.67	cl-sa-silt	silty sand	2180	1290	1.690
195	33P4-EOD	Ontario	PSC 12"sq	16.52	cl-sa-silt	cl-silt-till	2073	1779	1.165
196	33P5-EOD	Ontario	#14 Timber	8.66	cl-sa-silt	cl-silt-till	730	636	1.148
197	TRD22-EOD	Ontario	HP 12x74	6.13	sand	till	1575	1922	0.819
199	TRE22-EOD	Ontario	HP 12x74	7.83	sand	rock	2473	2558	0.967
201	TRP5X-EOD	Ontario	HP 12x53	7.68	sand	rock	1824	2153	0.847
								N	**7**
								Average	**1.208**
								SD	**0.399**
								COV	**0.330**
								Φ **β=2.33**	**0.639**
								Φ **β=3.0**	**0.493**

Table C-24 Pgh. PA CAPWAP (EOD) Data

No.	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
128	GF19-EOD	Pgh. PA	HP1Ox42	15.09	grvl-snd-slt	shale	1468	1770	0.829
129	GF110-EOD	Pgh. PA	HP12x74	15.15	grvl-snd-slt	shale	2224	2033	1.094
130	GF222-EOD	Pgh. PA	HP12x74	18.62	grvl-snd-slt	shale	2580	2277	1.133
131	GF224-EOD	Pgh. PA	Monotube	9.02	grvl-snd-slt	grvl-snd-slt		1864	
132	GF312-EOD	Pgh. PA	HP12x74	8.6	snd-grvl-shl	shale	1512	1802	0.839
133	GF313-EOD	Pgh. PA	HP10x57	9.6	snd-grvl-shl	claystone	1486	1984	0.749
134	GF412-EOD	Pgh. PA	HP12x74	10.24	grvl-snd-slt	claystone	1068	2024	0.528
135	GF413-EOD	Pgh. PA	HP10x57	10.55	grvl-snd-slt	claystone	1334	1904	0.701
136	GF414-EOD	Pgh. PA	HPIOx57	10.58	grvl-snd-slt	claystone	1601	2331	0.687
137	GF415-EOD	Pgh. PA	HP12x74	10.39	grvl-snd-slt	claystone	2046	2495	0.820
								N	**9**
								Average	**0.820**
								SD	**0.192**
								COV	**0.235**
								Φ **β=2.33**	**0.524**
								β=3.0	**0.423**

Table C-25 Wisconsin CAPWAP (EOD) Data

No.	Pile-Case Number	Location	Pile Type	Depth (m)	Soil Type		Davisson's Criteria (kN)	CAPWAP TEPWAP (kN)	Rdavisson / Rcapwap
					Side	Tip			
207	CHAT-EOD	Wisconsin	CEP 12.75"	37.49	sa-si clay	silty sand	2909	1735	1.677
210	CHA4-EOD	Wisconsin	CEP 12.75"	35.66	sa-si clay	silty sand	2251	1205	1.868
211	CHB2-EOD	Wisconsin	HP12x63	47.34	sa-si clay	silty sand	1343	489	2.746
217	CHB3-EOD	Wisconsin	HP12x63	43.31	sa-si clay	silty sand	890	467	1.906
221	CHC3-EOD	Wisconsin	CEP14"	47.3	sa-si clay	silty sand	836	489	1.710
224	CH4-EOD	Wisconsin	CEP9.63"	43.43	silty clay		1601	667	2.400
226	CH39-EOD	Wisconsin	CEP9.63"	43.28	silty clay	silty clay	2936	832	3.529
229	CH6-5B-EOD	Wisconsin	CEP9.63"	43.89	silty clay	silty sand	1673		
231	CH95B-EOD	Wisconsin	CEP9.63"	42.37	silty clay	sand & grvl	2473	983	2.516
								N	**8**
								Average	**2.294**
								SD	**0.637**
								COV	**0.278**
								Φ **β=2.33**	**1.349**
								β=3.0	**1.068**

APPENDIX D
Calibration Resistance Factor by Using FOSM for Driven Pile using Static Analysis

Table D-1a Calibration Resistance Factor for Driven Pile in Cohesionless Soil

LOCATION	$\frac{R_{Davisson}}{R_{Nordlund}}$	$\frac{R_{Davisson}}{R_{\beta}}$	$\frac{R_{Davisson}}{R_{Meyerhof}}$	$\frac{R_{Davisson}}{R_{Schmertmann\ SPT}}$
SURFRIDER CONDOMINIUM-FL	0.93	1.11	0.96	0.75
KARIDAS CONDOMINIUM #2-FL	0.79	0.66	0.15	0.48
BEACHES OF LONGBOAT-FL	2.54	2.42	0.4	1.54
VIENTA CONDOMINIUM-FL	1.64	1.68	0.19	0.68
ARVIDA HOTEL-FL	0.93	0.95	0.32	0.8
VERANDA HOTEL, SARASOTA-FL	1.75	1.83	0.23	0.9
LONGBOAT COVE, SARASOTA-FL	1.14	1.18	0.19	0.58
I-95 WEST PALM BEACH #1-FL	1.11	1.45	0.88	2.34
I-95 WEST PALM BEACH #2-FL	1.08	1.43	0.78	2.05
BLOUNT ISLAND SITE 215-FL	1.01	0.95	0.7	1.27
BLOUNT ISLAND SITE 316-FL	1.68	2.56	1.43	2.06
SIESTA KEY SARASOTA-FL	2.01	2.06	0.27	0.9
ST. JOHN'S RIVER (ASCE)-3B-FL	0.61	0.79	0.26	0.77
ST. JOHN'S RIVER (ASCE) 3C-FL	1.06	1.4	0.65	1.36
ST. AUGUSTINE (ASCE) 4A-FL	1.95	1.68	0.94	1.69
BLOUNT ISLAND TERM. B-20-FL	0.6	0.78	0.2	0.86
SARASOTA MEM. HOSPITAL-FL	1.28	1.12	1.37	0.93
PORT ORANGE BENT 2 PILE 6-FL	0.75	1.09	0.53	1.08
BLOUNT ISLAND TERM. B-21-FL	0.72	0.81	0.5	0.83
CAPE CANAVERAL T-6-FL	0.69	0.55	0.29	0.7
WEST BAY BRIDGE TP15-OH	0.42	0.6	1.17	1.42
ESCAMBIA RIVER BENT5-FL	0.48	0.69	1.17	1.68
ROOSEVELT BRIDGE A-FL	0.77	0.65	0.56	1.52
ROOSEVELT BRIDGE B-30-W-FL	0.92	0.67	0.82	1.89
BUCKMAN BRIDGE TS-19-FL	0.48	0.7	0.5	1.16
MARCO ISLAND TP2-FL	1.59	1.51	0.59	1.52
118 GRL Piles Bailey Fork, Bailey, TN	0.82	0.91	0.23	0.78
99 GRL Piles I-165/Water St Int, AL	0.79	1.01	0.52	1.09
99 GRL Piles I-165/Water St Int, AL	0.2	0.25	0.13	0.37
99 GRL Piles I-165/Water St Int, AL	1.21	1.53	1.12	2.43
99 GRL Piles I-165/Water St Int, AL	0.23	0.29	0.13	0.35
99 GRL Piles I-165/Water St Int, AL	0.47	0.66	0.59	0.96
Axial Pile-Mission Avenue, Viaduct, CA	1.93	2.11	1.04	1.63
LOAD TRANSFER #35-3, OK	1.61	1.62	0.98	2.79
Site 35, Pile 10, Reinforced Concrete	1.42	1.5	1.82	2.32
Jacksonville - Industrial zone # 1-FL	0.71	0.92	0.48	0.88
Jacksonville - Industrial zone # 1-FL				
Jacksonville - Industrial # 2-FL	0.84	1.19	0.61	0.94
Jacksonville - Industrial # 2-FL				
Number of Cases	**37**	**37**	**37**	**37**
Average	**1.06**	**1.17**	**0.64**	**1.25**
STD deviation	**0.55**	**0.56**	**0.42**	**0.62**
COV	**0.52**	**0.48**	**0.65**	**0.49**
Φ **β=2.33**	**0.37**	**0.45**	**0.17**	**0.46**
β=3.0	**0.26**	**0.32**	**0.11**	**0.33**

Table D-1b Calibration Resistance Factor for Driven Pile in Cohesionless Soil Using Florida Data Only

LOCATION		$\frac{R_{Davisson}}{R_{Nordlund}}$	$\frac{R_{Davisson}}{R_{\beta}}$	$\frac{R_{Davisson}}{R_{Meyerhof}}$	$\frac{R_{Davisson}}{R_{Schmertmann\ SPT}}$
SURFRIDER CONDOMINIUM-FL		0.93	1.11	0.96	0.75
KARIDAS CONDOMINIUM #2-FL		0.79	0.66	0.15	0.48
BEACHES OF LONGBOAT-FL		2.54	2.42	0.4	1.54
VIENTA CONDOMINIUM-FL		1.64	1.68	0.19	0.68
ARVIDA HOTEL-FL		0.93	0.95	0.32	0.8
VERANDA HOTEL, SARASOTA-FL		1.75	1.83	0.23	0.9
LONGBOAT COVE, SARASOTA-FL		1.14	1.18	0.19	0.58
I-95 WEST PALM BEACH #1-FL		1.11	1.45	0.88	2.34
I-95 WEST PALM BEACH #2-FL		1.08	1.43	0.78	2.05
BLOUNT ISLAND SITE 215-FL		1.01	0.95	0.7	1.27
BLOUNT ISLAND SITE 316-FL		1.68	2.56	1.43	2.06
SIESTA KEY SARASOTA-FL		2.01	2.06	0.27	0.9
ST. JOHN'S RIVER (ASCE)-3B-FL		0.61	0.79	0.26	0.77
ST. JOHN'S RIVER (ASCE) 3C-FL		1.06	1.4	0.65	1.36
ST. AUGUSTINE (ASCE) 4A-FL		1.95	1.68	0.94	1.69
BLOUNT ISLAND TERM. B-20-FL		0.6	0.78	0.2	0.86
SARASOTA MEM. HOSPITAL-FL		1.28	1.12	1.37	0.93
PORT ORANGE BENT 2 PILE 6-FL		0.75	1.09	0.53	1.08
BLOUNT ISLAND TERM. B-21-FL		0.72	0.81	0.5	0.83
CAPE CANAVERAL T-6-FL		0.69	0.55	0.29	0.7
ESCAMBIA RIVER BENT5-FL		0.48	0.69	1.17	1.68
ROOSEVELT BRIDGE A-FL		0.77	0.65	0.56	1.52
ROOSEVELT BRIDGE B-30-W-FL		0.92	0.67	0.82	1.89
BUCKMAN BRIDGE TS-19-FL		0.48	0.7	0.5	1.16
MARCO ISLAND TP2-FL		1.59	1.51	0.59	1.52
Jacksonville - Industrial zone # 1-FL		0.71	0.92	0.48	0.88
Jacksonville - Industrial zone # 1-FL					
Jacksonville - Industrial # 2-FL		0.84	1.19	0.61	0.94
Jacksonville - Industrial # 2-FL					
N		**27**	**27**	**27**	**27**
Average		**1.113**	**1.216**	**0.591**	**1.191**
STD deviation		**0.525**	**0.545**	**0.358**	**0.508**
COV		**0.471**	**0.448**	**0.606**	**0.427**
Φ	**β=2.33**	**0.43**	**0.50**	**0.17**	**0.51**
	β=3.0	**0.31**	**0.36**	**0.12**	**0.38**

Table D-2a Calibration Resistance Factor for Driven Pile in Cohesive Soil

LOCATION		$\frac{R_{Davisson}}{R_{\alpha API\ revised}}$	$\frac{R_{Davisson}}{R_{\alpha Tomlinson}}$	$\frac{R_{Davisson}}{R_{\lambda}}$
ACOSTA BRIDGE PEIR H2-FL		1.57	2.18	1.35
BRIDGE SITE 3046A, Hinds, MS		0.77	1.35	0.55
Dist. 08 P 455-03-04, 455-05-03 TP33,		0.52	0.4	0.55
Dist. 61 P 50-05-15 TP1, Ascension, LA		0.86	0.77	0.83
Dist. 61 P 742-01-39, East Baton, LA		0.64	0.64	0.59
Axial Pile-Mission Avenue, Viaduct, CA		1.58	1.65	0.97
BRIDGE SITE 1067, HINDS, MS		0.94	0.92	0.59
BRIDGE SITE 1068, HINDS, MS		0.87	1.64	0.61
BRIDGE SITE 1072A, HINDS, MS		0.84	0.85	0.59
BRIDGE SITE 3024, HINDS, MS		0.55	0.59	0.36
Dist. 02 P 7-03-40 TP5, St. Charles LA		0.73	0.89	0.95
Dist. 02 P 855-14-7 and P 855-14-5 , LA		1.26	1.47	1.01
Dist. 03 P 455-02-04 TP2, St. Landry LA		0.8	0.52	0.73
065-90-0024_and_855-04-0046_ TP5-LA		1.21	1.08	1.24
424-05-0081_Bayou_Boeuf_West_; TP1-LA		0.75	0.86	0.73
424-06-0005_Bayou_Boeuf_East_ F1-LA		0.92	0.57	0.95
424-06-0005_Bayou_Boeuf_East_ F2;-LA		0.94	0.63	0.99
424-06-0005_Bayou_Boeuf_East_ F5-LA		0.61	0.38	0.67
424-06-0005_Bayou_Boeuf_East_ F6-LA		0.57	0.4	0.75
N		**19**	**19**	**19**
Average		**0.89**	**0.94**	**0.79**
Standard deviation		**0.31**	**0.50**	**0.25**
COV		**0.35**	**0.54**	**0.32**
Φ	**β=2.33**	**0.45**	**0.32**	**0.30**
	β=3.0	**0.34**	**0.22**	**0.21**

Table D-2b Calibration Resistance Factor for Driven Pile in Cohesive Soil Using Louisiana Data Only

LOCATION		$\frac{R_{Davisson}}{R_{\alpha API\ revised}}$	$\frac{R_{Davisson}}{R_{\alpha Tomlinson}}$	$\frac{R_{Davisson}}{R_{\lambda}}$
Dist. 08 P 455-03-04, 455-05-03 TP33-LA		0.52	0.4	0.55
Dist. 61 P 50-05-15 TP1, Ascension-LA		0.86	0.77	0.83
Dist. 61 P 742-01-39, East Baton-LA		0.64	0.64	0.59
Dist. 02 P 7-03-40 TP5, St. Charles -LA		0.73	0.89	0.95
Dist. 02 P 855-14-7 and P 855-14-5-LA		1.26	1.47	1.01
Dist. 03 P 455-02-04 TP2, St. Landry-LA		0.8	0.52	0.73
065-90-0024_and_855-04-0046_ TP5-LA		1.21	1.08	1.24
424-05-0081_Bayou_Boeuf_West_; TP1-LA		0.75	0.86	0.73
424-06-0005_Bayou_Boeuf_East_ F1-LA		0.92	0.57	0.95
424-06-0005_Bayou_Boeuf_East_ F2-LA		0.94	0.63	0.99
424-06-0005_Bayou_Boeuf_East_ F5-LA		0.61	0.38	0.67
424-06-0005_Bayou_Boeuf_East_ F6-LA		0.57	0.4	0.75
N		**12**	**12**	**12**
Average		**0.818**	**0.718**	**0.833**
Standard deviation		**0.236**	**0.322**	**0.201**
COV		**0.289**	**0.449**	**0.241**
Φ	**β=2.33**	**0.47**	**0.29**	**0.53**
	β=3.0	**0.37**	**0.21**	**0.42**

Table D-3a Calibration Resistance Factor for Driven Pile in Mixed Soil

LOCATION	$\frac{R_{Davisson}}{R_{\alpha\ Tomlinson\ Nordlund\ Thurman}}$	$\frac{R_{Davisson}}{R_{\alpha-API\ revised\ Nordlund\ Thurman}}$	$\frac{R_{Davisson}}{R_{\beta-Thurman}}$	$\frac{R_{Davisson}}{R_{Schmertmann\ SPT}}$	$\frac{R_{Davisson}}{R_{Schmertmann\ CPT}}$
APP. BAY BRIDGE BENT 101	0.97	1.11	1.03	3.58	
APP. BAY BRIDGE BENT 133	1.12	0.72	0.62	2.07	
I-275 34th ST. PINELLAS-FL	0.5	0.55	0.71	0.88	
DeSOTA CONDOMINIUM MS.-FL		1.17	1.22	1.16	
WASHINGTON CONDOMINIUM		0.39	0.46	0.49	
SUNSHINE SKYWAY SITE 1 A-FL				1.05	
SUNSHINE SKYWAY SITE 1 B-FL				0.99	
SUNSHINE SKYWAY SITE 3-FL				1.51	
SUNSHINE SKYWAY SITE 10-FL	1.17	0.95	0.81	1.88	
SUNSHINE SKYWAY SITE 13 A-FL				2.35	
FLORENCE/MARION 3 ASD		1.56	1.88	1.71	
FLORENCE / MARION 3 BSD	0.46	0.63	0.6	1.2	
FLORENCE / MARION 3 CSD	0.45	0.64	0.66	1	
NORTHEAST VILLA MIRADA - 6-FL		1.22	1.24	1.71	
SEAWAY HOTELS, SAND KEY-FL				2.68	
HOWARD FRANKLAND / LS3-FL	0.53	0.99	0.85	2.23	
CHOCTAWHATCHEE P-5-FL		0.85	0.99	2.76	
CHOCTAWHATCHEE P-11-FL		1.01	1.4	2.49	
CHOCTAWHATCHEE P-17-FL		1.08	1.42	3.13	
CHOCTAWHATCHEE P-23-FL		0.43	0.63	0.91	
CHOCTAWHATCHEE P-29-FL		0.58	0.86	1.38	
CHOCTAWHATCHEE P-35-FL		0.92	1.43	2.17	
HOWARD FRANK. / LS4 SHORT		3.33	3.87	5.21	
CHOCTAWHATCHEE P-41-FL	1.35	1.32	1.34	3.52	
CHOCTAWHATCHEE FSB-26-FL		0.38	0.55	1.1	
CAPE CANAVERAL T-7-FL		0.62	0.67	0.96	
CAPE CANAVERAL T-14-FL		0.9	1.07	1.34	
WHITE CITY BRIDGE TP3-PA		2.56	2.82	3.66	
HOWARD FRANK. / LS4 LONG-FL?				0.5	
WHITE CITY BRIDGE TP6-PA		1.53	1.69	1.85	
ACOSTA BRIDGE PEIR F6-FL		0.88	1.01	1.49	
ACOSTA BRIDGE PEIR G13_FL				1.83	
BUCKMAN BRIDGE TS-13-FL		0.42	0.47	1.19	
BUCKMAN BRIDGE TS-24-FL	0.51	0.52	0.8	1.07	
BUCKMAN BRIDGE TS-29-FL		0.47	0.61	1.16	
APPALACHICOLA RIVER PIER14-FL		0.76	1.01	1.89	
APPALACHICOLA RIVER PIER25-FL		1.15	1.44	2.81	
MARINA BAY CLUB TP7-FL				1.85	
APPALACHICOLA BAY BENT 41-FL		1.51	1.65	3.99	
ST. MARISSA CONDO. TP8 & Pile 20-FL				1.52	

Table D-3a (cont.)

GEORGIA/FLORIDA BOUNDARY-FL				0.76	
JACKSONVILLE SITE B-FL				1.83	
JACKSONVILLE SITE D-FL				1.4	
SAINT JOHN RIVER SITE F-FL				1.09	
LONGBOAT KEY - SARASOTA-FL	0.51	0.75	0.7	0.88	
SUNSHINE SKYWAY SITE 13 B-FL				1.37	
116 GRL Piles-164/Cimaron Rvr Br, OK	0.47	0.76	0.58	1.01	
116 GRL Piles-164/Cimaron Rvr Br, OK	0.75	1.35	1.06	1.82	
119 GRL Piles-White City Bridge, FL		1.32	1.39	2.51	
119 GRL Piles-White City Bridge, FL		1.26	1.53	2.32	
123 GRL Piles-Dawhoo River Bridge, SC	1.28	1.27	0.92	1.59	
123 GRL Piles-Dawhoo River Bridge, SC	0.35	0.35	0.29	0.63	
124 GRL Piles-Socastee W. Way Br, SC		0.85	0.92	1.41	
125 GRL Piles-Doughty St Prk Gar, SC	1.07	0.84	0.76	1.87	
126 GRL Piles-Battery Creek, SC		0.82	1.11	1.73	
126 GRL Piles-Battery Creek, SC				0.87	
204 GRL Piles-C&D Canal, Pier 17, DE		0.64	0.79	1.33	
Axial Pile-Mission Avenue, Viaduct, CA	1.36	1.47	1.51	1.41	
Doheny Park Rd U.C. Sta 451+85.5, CA		0.4	0.39	0.51	
Luling Bridge; TP2-LA	1.66	0.65	0.65	2.92	
Luling Bridge; TP3; Circular void-LA		0.79	0.81	6.2	
Luling Bridge; TP4; Circular void-LA	1.72	0.66	0.65	3.42	
Luling Bridge; TP5-LA	1.84	0.71	0.69	3.61	
Luling Bridge; TP6-LA	1.74	0.71	0.69	3.59	
Luling Bridge; TP7-LA	1.8	0.72	0.71	3.76	
Orlando International Airport; D22-FL		1.43	1.54	2.31	
Site 33, Pile 3, Reinforced Concrete		0.47	0.48	0.67	
Site 33, Pile 4, Reinforced Concrete		1.31	1.18	1.47	
Ft Myers-FL		1.12	1.27	1.24	
					1.23
Apalachicola River Bridge - Pier 3-FL		0.76	0.94	1.83	
					0.86
Apalachicola Bay Bridge – Bent 22-FL	1.55	0.94	0.81	2.3	
					1.21
Apalachicola Bay Bridge – Bent 16-FL		0.56	0.71		0.98
Port Orange - Bent 19-FL		0.87	1.29	1.01	
					0.28
Choctahatchee Bay, FL3		0.83	1.19	2.79	
					0.83
Choctahatchee Bay, FL26	2.28	1.91	2.41	6.24	
					1.69
065-90-0024_and_855-04-0046_ Tp1-LA	0.68	0.66	0.61		0.69
065-90-0024_and_855-04-0046_ Tp2-LA	0.45	0.48	0.39		0.52
065-90-0024_and_855-04-0046_ TP3-LA	0.92	0.81	0.72		0.86
065-90-0024_and_855-04-0046_ TP4-LA	1.02	0.82	0.66		0.94
260-05-0020_Tickfaw_River_; TP1-LA	1.09	1.17	0.94		1.22

Table D-3a (cont.)

262-06-09_Tickfaw_River_ #1; TP1-LA			0.24	0.42		0.55
262-06-09_Tickfaw_River_ #1; TP2-LA			0.21	0.35		0.36
283-09-52_New_Orleans-LA			0.82	0.77		1.26
424-05-0078_Bayou_Boeuf_Main_; TP2-LA			0.74	0.69		1.02
424-05-0078_Bayou_Boeuf_Main_; TP5-LA		1.06	1.42	1.11		2
424-05-0081_Bayou_Boeuf_West_; TP2-LA			0.49	0.42		0.59
424-05-0081_Bayou_Boeuf_West_; TP3-LA			0.82	0.72		1.26
424-05-0081_Bayou_Boeuf_West_; TP4-LA		0.54	0.71	0.52		0.65
424-05-0087_Bayou_Ramos_ TP1-LA			0.75	0.7		0.73
424-05-0087_Bayou_Ramos_ TP2-LA			0.47	0.68		0.87
424-05-0087_Bayou_Ramos_ TP3-LA			0.43	0.55		0.77
424-05-0087_Bayou_Ramos_ TP4-LA			0.57	0.86		0.76
424-05-0087_Bayou_Ramos_ TP5-LA			0.49	0.47		0.65
424-05-0087_Bayou_Ramos_ TP7-LA		1.28	0.68	0.58		0.79
424-06-0005_Bayou_Boeuf_East_ F3-LA		0.5	0.76	0.57		0.95
424-06-0005_Bayou_Boeuf_East_ F4-LA		0.53	0.72	0.51		0.96
424-07-0009_Gibson_Raceland_ TP1-LA			0.88	0.77		0.72
424-07-0009_Gibson_Raceland_ TP4-LA			0.61	0.56		0.88
450-366-02_Luling_Bridge-LA			0.47	0.48		0.65
855-14-13_Houma-LA		0.57	0.76	0.58		1.18
N		**34**	**85**	**85**	**74**	**32**
Average		**1.00**	**0.88**	**0.93**	**1.97**	**0.90**
Standard deviation		**0.52**	**0.47**	**0.55**	**1.21**	**0.35**
COV		**0.52**	**0.54**	**0.59**	**0.61**	**0.39**
Φ	**β=2.33**	**0.35**	**0.30**	**0.28**	**0.57**	**0.42**
	β=3.0	**0.25**	**0.21**	**0.19**	**0.38**	**0.31**

Table D-3b Calibration Resistance Factor for Driven Pile in Mixed Soil Using Florida Data Only

LOCATION	$\frac{R_{Davisson}}{R_{\alpha\ \text{Tomlinson Nordlund Thurman}}}$	$\frac{R_{Davisson}}{R_{\alpha-\text{API revised Nordlund Thurman}}}$	$\frac{R_{Davisson}}{R_{\beta-\text{Thurman}}}$	$\frac{R_{Davisson}}{R_{\text{Schmertmann SPT}}}$	$\frac{R_{Davisson}}{R_{\text{Schmertmann CPT}}}$
APP. BAY BRIDGE BENT 101	0.97	1.11	1.03	3.58	
APP. BAY BRIDGE BENT 133	1.12	0.72	0.62	2.07	
I-275 34th ST. PINELLAS-FL	0.5	0.55	0.71	0.88	
DeSOTA CONDOMINIUM MS.-FL		1.17	1.22	1.16	
WASHINGTON CONDOMINIUM		0.39	0.46	0.49	
SUNSHINE SKYWAY SITE 1 A-FL				1.05	
SUNSHINE SKYWAY SITE 1 B-FL				0.99	
SUNSHINE SKYWAY SITE 3-FL				1.51	
SUNSHINE SKYWAY SITE 10-FL	1.17	0.95	0.81	1.88	
SUNSHINE SKYWAY SITE 13 A-FL				2.35	
FLORENCE/MARION 3 ASD		1.56	1.88	1.71	
FLORENCE / MARION 3 BSD	0.46	0.63	0.6	1.2	
FLORENCE / MARION 3 CSD	0.45	0.64	0.66	1	

Table D-3b (cont.)

NORTHEAST VILLA MIRADA – 6-FL		1.22	1.24	1.71	
SEAWAY HOTELS, SAND KEY-FL				2.68	
HOWARD FRANKLAND / LS3-FL	0.53	0.99	0.85	2.23	
CHOCTAWHATCHEE P-5-FL		0.85	0.99	2.76	
CHOCTAWHATCHEE P-11-FL		1.01	1.4	2.49	
CHOCTAWHATCHEE P-17-FL		1.08	1.42	3.13	
CHOCTAWHATCHEE P-23-FL		0.43	0.63	0.91	
CHOCTAWHATCHEE P-29-FL		0.58	0.86	1.38	
CHOCTAWHATCHEE P-35-FL		0.92	1.43	2.17	
HOWARD FRANK. / LS4 SHORT		3.33	3.87	5.21	
CHOCTAWHATCHEE P-41-FL	1.35	1.32	1.34	3.52	
CHOCTAWHATCHEE FSB-26-FL		0.38	0.55	1.1	
CAPE CANAVERAL T-7-FL		0.62	0.67	0.96	
CAPE CANAVERAL T-14-FL		0.9	1.07	1.34	
HOWARD FRANK. / LS4 LONG-FL?				0.5	
ACOSTA BRIDGE PEIR F6-FL		0.88	1.01	1.49	
ACOSTA BRIDGE PEIR G13_FL				1.83	
BUCKMAN BRIDGE TS-13-FL		0.42	0.47	1.19	
BUCKMAN BRIDGE TS-24-FL	0.51	0.52	0.8	1.07	
BUCKMAN BRIDGE TS-29-FL		0.47	0.61	1.16	
APPALACHICOLA RIVER PIER14-FL		0.76	1.01	1.89	
APPALACHICOLA RIVER PIER25-FL		1.15	1.44	2.81	
MARINA BAY CLUB TP7-FL				1.85	
APPALACHICOLA BAY BENT 41-FL		1.51	1.65	3.99	
ST. MARISSA CONDO. TP8 & Pile 20-FL				1.52	
GEORGIA/FLORIDA BOUNDARY-FL				0.76	
JACKSONVILLE SITE B-FL				1.83	
JACKSONVILLE SITE D-FL				1.4	
SAINT JOHN RIVER SITE F-FL				1.09	
LONGBOAT KEY – SARASOTA-FL	0.51	0.75	0.7	0.88	
SUNSHINE SKYWAY SITE 13 B-FL				1.37	
119 GRL Piles-White City Bridge, FL		1.32	1.39	2.51	
119 GRL Piles-White City Bridge, FL		1.26	1.53	2.32	
Orlando International Airport; D22-FL		1.43	1.54	2.31	
Site 33, Pile 3, Reinforced Concrete		0.47	0.48	0.67	
Site 33, Pile 4, Reinforced Concrete		1.31	1.18	1.47	
Ft Myers-FL		1.12	1.27	1.24	
Apalachicola River Bridge - Pier 3-FL		0.76	0.94	1.83	
Apalachicola Bay Bridge - Bent 22-FL	1.55	0.94	0.81	2.3	
Apalachicola Bay Bridge - Bent 16-FL		0.56	0.71		0.98
Port Orange - Bent 19-FL		0.87	1.29	1.01	
Choctahatchee Bay, FL3		0.83	1.19	2.79	
Choctahatchee Bay, FL26	2.28	1.91	2.41	6.24	
					1.69
N	**12**	**42**	**42**	**55**	**7**
Average	**0.95**	**0.97**	**1.11**	**1.87**	**1.01**

Table D-3b (cont.)

Standard deviation		**0.57**	**0.52**	**0.61**	**1.10**	**0.44**
COV		**0.60**	**0.54**	**0.54**	**0.59**	**0.43**
Φ	**β=2.33**	**0.28**	**0.33**	**0.37**	**0.56**	**0.43**
	β=3.0	**0.19**	**0.23**	**0.26**	**0.38**	**0.32**

Table D-3c Calibration Resistance Factor for Driven Pile in Mixed Soil Using Lousiana Data Only

LOCATION	$\frac{R_{Davisson}}{R_{\alpha\ Tomlinson\ Nordlund\ Thurman}}$	$\frac{R_{Davisson}}{R_{\alpha-API\ revised\ Nordlund\ Thurman}}$	$\frac{R_{Davisson}}{R_{\beta-Thurman}}$	$\frac{R_{Davisson}}{R_{Schmertmann\ SPT}}$	$\frac{R_{Davisson}}{R_{Schmertmann\ CPT}}$
Luling Bridge; TP2-LA	1.66	0.65	0.65	2.92	
Luling Bridge; TP3; Circular void-LA		0.79	0.81	6.2	
Luling Bridge; TP4; Circular void-LA	1.72	0.66	0.65	3.42	
Luling Bridge; TP5-LA	1.84	0.71	0.69	3.61	
Luling Bridge; TP6-LA	1.74	0.71	0.69	3.59	
Luling Bridge; TP7-LA	1.8	0.72	0.71	3.76	
065-90-0024_and_855-04-0046_ Tp1-LA	0.68	0.66	0.61		0.69
065-90-0024_and_855-04-0046_ Tp2-LA	0.45	0.48	0.39		0.52
065-90-0024_and_855-04-0046_ TP3-LA	0.92	0.81	0.72		0.86
065-90-0024_and_855-04-0046_ TP4-LA	1.02	0.82	0.66		0.94
260-05-0020_Tickfaw_River_; TP1-LA	1.09	1.17	0.94		1.22
262-06-09_Tickfaw_River_ #1; TP1-LA		0.24	0.42		0.55
262-06-09_Tickfaw_River_ #1; TP2-LA		0.21	0.35		0.36
283-09-52_New_Orleans-LA		0.82	0.77		1.26
424-05-0078_Bayou_Boeuf_Main_; TP2-LA		0.74	0.69		1.02
424-05-0078_Bayou_Boeuf_Main_; TP5-LA	1.06	1.42	1.11		2
424-05-0081_Bayou_Boeuf_West_; TP2-LA		0.49	0.42		0.59
424-05-0081_Bayou_Boeuf_West_; TP3-LA		0.82	0.72		1.26
424-05-0081_Bayou_Boeuf_West_; TP4-LA	0.54	0.71	0.52		0.65
424-05-0087_Bayou_Ramos_ TP1-LA		0.75	0.7		0.73
424-05-0087_Bayou_Ramos_ TP2-LA		0.47	0.68		0.87
424-05-0087_Bayou_Ramos_ TP3-LA		0.43	0.55		0.77
424-05-0087_Bayou_Ramos_ TP4-LA		0.57	0.86		0.76
424-05-0087_Bayou_Ramos_ TP5-LA		0.49	0.47		0.65
424-05-0087_Bayou_Ramos_ TP7-LA	1.28	0.68	0.58		0.79
424-06-0005_Bayou_Boeuf_East_ F3-LA	0.5	0.76	0.57		0.95
424-06-0005_Bayou_Boeuf_East_ F4-LA	0.53	0.72	0.51		0.96
424-07-0009_Gibson_Raceland_ TP1-LA		0.88	0.77		0.72
424-07-0009_Gibson_Raceland_ TP4-LA		0.61	0.56		0.88
450-366-02_Luling_Bridge-LA		0.47	0.48		0.65
855-14-13_Houma-LA	0.57	0.76	0.58		1.18
N	**16**	**31**	**31**	**6**	**25**
Average	**1.09**	**0.68**	**0.64**	**3.92**	**0.87**
Standard deviation	**0.52**	**0.23**	**0.16**	**1.16**	**0.33**
COV	**0.48**	**0.34**	**0.26**	**0.30**	**0.38**
Φ **β=2.33**	**0.42**	**0.35**	**0.39**	**2.23**	**0.41**
β=3.0	**0.30**	**0.27**	**0.31**	**1.75**	**0.31**

APPENDIX E
Nominal and Measure Capacity of Driven Pile from Vietnam

Table E-1 Summary driven pile data from North, Central and south of Vietnam

No	Name of Project	Location	Soil type	Name	Dimention (mm)	Pile Length (m)
NP-C1	32 Hang Trong-Hanoi	Hanoi	Clay	No77	20x20	12
NP-C2	-	North Plain		No22	20x20	12
NP-C3	61 Lac Trung-Hanoi	Hanoi	Clay	No41-A	25x25	22
NP-C4	-	North Plain		No50-B	25x25	36
NP-C5	-	-		No181-B	25x25	32
NP-C6	-	-		No311-B	25x25	22
NP-C7	-	-		No416-B	25x25	22
NP-C8	Sai Dong-Gia Lam-Hanoi	Hanoi	Clay	F-13	25x25	21.8
NP-C9	-	North Plain		B-13	25x25	22.5
NP-C10	-	-		B-9	25x25	22
NP-C11	-	-		E-5	25x25	22.1
NP-C12	-	-		B-1	25x25	21.5
NP-C13	-	-		E-1	25x25	21.8
NP-C14	NguPhuc-Kim Thanh	Hai Duong	Clay	No2	25x25	16
NP-C15	Hai Duong	North Plain		No3	25x25	16
NP-C16	-	-		No4	25x25	16
NP-C17	Truong Hoc-Nam Sach	Hai Duong	Clay	TN01	20x20	11
NP-C18	Hai Duong	North Plain		TN02	20x20	11
NP-C19	Nha Lam Viec-Nam Sach	Hai Duong	Clay	TN01	25x25	12
NP-C20	Hai Duong	North Plain		TN02	25x25	12
NP-C21	Duong 395 -Hai Duong	Hai Duong	Clay	TN1-VH	30x30	23
NP-C22		North Plain		TN1-SAT	30x30	23
NP-C23	16 Cat Bi-HaiPhong	HaiPhong	Clay	No1	30x30	30.2
NM-C24	Nhacong vu Cong An-Lao Cai	Lao Cai	Clay	TN1-011	25x25	10
NM-C25	-	North		TN2-051	25x25	10.8
NM-C26	-	Mountain		TN3-114	25x25	13.6
NM-C27	-	-		TN4-172	25x25	12
NM-C28	Viet Tri-VinhPhu	VinhPhu	Clay	TN02	30x30	19.6
NM-C29		North		TN03	30x30	17.5
NM-C30		Mountain		TN04	30x30	18
NM-C31		-		TN05	30x30	18.5
NM-C32		-		TN03B	30x30	19
NM-C33	Vung Dang-QuangNinh	QuangNinh	Clay	N01	25x25	11.5
NM-C34		North		N02	25x25	6.5
NM-C35		Mountain		N03	25x25	6.2
NM-C36		-		N04	25x25	9.36
NM-C37		-		N02	25x25	10
NM-C38		-		N03	25x25	10
NP-C39	Thinh Long-Nam Dinh	Nam Dinh	Clay	M1PD4	D=45	37.2
NP-C40	-	North Plain		I21PD4	D=45	37.2
NP-C41	-	-		I1PD3	D=45	37.2
NP-C42	-	-		B40PD4	D=45	37.2
NP-C43	-	-		B13PD3	D=45	37.2

Table E-1 (cont.)

NP-C44	-	-		C23-PD1	40x40	39.2
NP-C45	-	-		K2-PD2	40x40	39.1
NP-C46	-	-		C42-Tuonggoc	40x40	31
NP-C47	-	-		D1-PD5	40x40	31
NP-C48	-	-		D38-150	40x40	37
NP-C49	-	-		B38-30	40x40	37.1
NP-S1	134 QuanThanh-Hanoi	Hanoi	Sand	TN1	20x20	15
NP-S2	-	North Plain		TN2	20x20	22.3
NP-S3	-	-		TN3	20x20	22.6
NP-S4	Nha may panasonic-Hanoi	Hanoi	Sand	TN1	30x30	25
NP-S5	-	North Plain		TN2	30x30	25
NP-S6	-	-		TN3	30x30	25
NP-S7	-	-		TN4	30x30	25
NP-S8	-	-		TN5	30x30	25
NP-S9	-	-		TN6	30x30	25
NP-S10	-	-		TN7	30x30	25
NP-S11	-	-		TN8	30x30	25
NP-S12	-	-		TN9	30x30	25
NP-S13	-	-		TN10	30x30	25
NP-S14	-	-		TN11	30x30	25
NP-S15	-	-		TN12	30x30	25
NP-S16	-	-		TN13	30x30	25
NP-S17	-	-		TN14	30x30	25
NP-S18	-	-		TN15	30x30	25
NP-S19	-	-		TN16	30x30	25
NP-S20	CT20A-Viet Hung-Hanoi	Hanoi	Sand	No133-CT20A1	25x25	25
NP-S21	-	North Plain		No37-CT20A2	25x25	25
NP-S22	-	-		No133-CT20A4	25x25	25
NP-S23	-	-		No66-CT20A	25x25	25
NP-S24	-	-		No37-CT20A1	25x25	25
NP-S25	-	-		No133-CT20A1	25x25	25
NP-S26	-	-		No37-CT20A2	25x25	25
NP-S27	-	-		No133-CT20A2	25x25	25
NP-S28	-	-		No37-CT20A3	25x25	25
NP-S29	-	-		No133-CT20A3	25x25	25
NP-S30	-	-		No37-CT20A4	25x25	25
NP-S31	-	-		No133-CT20A4	25x25	25
NP-S32	CT20B-Viet Hung-Hanoi	Hanoi	Sand	N01	40x40	36
NP-S33	-	North Plain		N91	40x40	36
NP-S34	-	-		N164	40x40	36
NP-S35	Yen Thuong-Gia Lam-Hanoi	Hanoi	Sand	No122	25x25	12
NP-S36		North Plain		No239	25x25	12
NP-S37		-		No56	25x25	12
NP-S38		-		No112	25x25	12

Table E-1 (cont.)

NP-S39		-		No161	25x25	12
NP-S40	Lai Vu-Hai Duong	Hai Duong	Sand	No77	25x25	13
NP-S41	Thanh Dong-Hai Duong	Hai Duong	Sand	No30	25x25	32.5
NP-S42		North Plain		No78	25x25	32.6
NP-S43		-		No80	25x25	33.3
NP-S44	Tran Phu-Hai Duong	Hai Duong	Sand	TN-24	25x25	29
NP-S45		North Plain		TN-70	25x25	29
NP-S46		-		TN-134	25x25	29
NP-S47	Truong congnhankythuat	Hung Yen	Sand	C2-No16	30x30	32.5
NP-S48	Hung Yen	North Plain		D7-No65	30x30	33
NP-S49		-		C10-No102	30x30	31.5
NP-S50		-		D14-No140	30x30	32.4
NP-S51	Tru so lam viec so thuongmai	Hai Duong	Sand	N037	25x25	11.9
NP-S52	Hai Duong	North Plain		N090	25x25	11.4
NP-S53		-		N0208	25x25	12.1
NP-S54		-		N0282	25x25	14.2
NP-M1	My Dinh-TuLiem-hanoi	Hanoi	Mixed	N01-C144	35x35	23.8
NP-M2		North Plain		N02-C65	35x35	22.4
NP-M3	81 Tran Hung Dao-Hanoi	Hanoi	Mixed	No248	35x35	21.4
NP-M4	-	North Plain		No129	35x35	21.8
NP-M5	-	-		No53	35x35	21.8
NP-M6	299 Duong CauGiay-Hanoi	Hanoi	Mixed	No64	35x35	25
NP-M7	-	North Plain		No185	35x35	26.6
NP-M8	-	-		No132	35x35	26.8
NP-M9	-	-		No52	35x35	25.2
NP-M10	335 Duong CauGiay-Hanoi	Hanoi	Mixed	TN05-108	35x35	-
NP-M11	Bo KeHoachDauTu-Hanoi	Hanoi	Mixed	N3-51	30x30	35+2
NP-M12	-	North Plain		N9-92	30x30	35+2
NP-M13	-	-		N8-139	30x30	35+2
NP-M14	-	-		N2-233	30x30	35+2
NP-M15	-	-		N4-558	30x30	35+2
NP-M16	-	-		N7-682	30x30	35+2
NP-M17	-	-		N5-874	30x30	35+2
NP-M18	Me Tri-TuLiem-Hanoi	Hanoi	Mixed	NT06	25x25	27
NP-M19	-	North Plain		NT05	25x25	27
NP-M20	-	-		NT04	25x25	27
NP-M21	-	-		NT03	25x25	27
NP-M22	-	-		NT02	25x25	27
NP-M23	-	-		NT01	25x25	27
NP-M24	DH KienTruc Hanoi	Hanoi		N01-10F	20x20	12
NP-M25	-	North Plain		N02-7E	20x20	12
NP-M26	CC1-Dich Vong-CauGiay-Hanoi	Hanoi	Mixed	NT1	35x35	25.4
NP-M27	-	North Plain		NT2	35x35	20.4
NP-M28	-	-		NT3	35x35	19
NP-M29	-	-		N-4	35x35	20
NP-M30	-	-		N-5	35x35	20
NP-M31	Nha may dong tau Song Hong	Hanoi	Mixed	A1-5	35x35	25
NP-M32	Hanoi	North Plain		B1-2	35x35	25
NP-M33	-	-		A5-2	35x35	25

Table E-1 (cont.)

NP-M34	-	-		A10-5	35x35	25
NP-M35	-	-		B5-2	35x35	25
NP-M36	-	-		B10-2	35x35	25
NP-M37	-	-		A1	35x35	21.4
NP-M38	-	-		A29	35x35	19
NP-M39	-	-		A60	35x35	25.5
NP-M40	-	-		A55	35x35	19.5
NP-M41	CT14K-Viet Hung-Hanoi	Hanoi	Mixed	No62	40x40	36.4
NP-M42	-	North Plain		No55	40x40	33.5
NP-M43	-	-		No172	40x40	35.6
NP-M44	-	-		No336	40x40	32.9
NP-M45	-	-		No243	40x40	33.8
NP-M46	Van Mo-HaDong-Hanoi	Hanoi	Mixed	SHC220-D8	25x25	11.6
NP-M47	-	North Plain		SHC480-C11	25x25	12.4
NP-M48	-	-		SHC540-C15	25x25	11.75
NP-M49	-	-		SHC103-B13	25x25	12
NP-M50	-	-		SHC28-E4	25x25	11.5
NP-M51	-	-		SHC355-B2	25x25	11.3
NP-M52	-	-		SHC410-C6	25x25	11.5
NP-M53	27 Hang Bai - Hanoi	Hanoi	Mixed	NT1-HB	25x25	21,8
NP-M54	192B QuanThanh - Hanoi	Hanoi	Mixed	5QT	30x30	21,5
NP-M55	-	North Plain		7QT	30x30	21
NP-M56	DHXD- Hanoi	Hanoi	Mixed	NT06	35x35	19
NP-M57	-	North Plain		NT10	35x35	13
NP-M58	VinhPhuc-Hanoi	Hanoi	Mixed	TN1	25x25	15
NP-M59		North Plain		TN2	25x25	15
NP-M60		-		TN2	25x25	15
NP-M61	Sieuthi 7 tang- Hai Duong	Hai Duong	Mixed	TN01-103	30x30	38.4
NP-M62		North Plain		TN2-60	30x30	38.1
NP-M63	Cau Lac boHuu Tri Nguyen Trai	Hai Duong	Mixed	D1-Cx7	20x20	10.8
NP-M64	Hai Duong	North Plain		D5-Fx12	20x20	10.9
NP-M65	-	-		D2-Ex5	20x20	11
NP-M66	Dai Vien Thong Thanh Ha	Hai Duong	Mixed	No1	25x25	17
NP-M67	Hai Duong	North Plain		No2	25x25	17
NP-M68	KyThucXa-Truong Cao Dang	Hai Duong	Mixed	TN1-129	25x25	39
NP-M69	Hai Duong	North Plain		TN2-95	25x25	39
NP-M70	-	-		TN3-32	25x25	39
NP-M71	Lai Cach-Cam Giang-Hai Duong	Hai Duong	Mixed	TN57	25x25	35
NP-M72		North Plain		TN355	25x25	40
NP-M73		-		TN312	25x25	24.5
NP-M74		-		TN121	25x25	23
NP-M75	Great Wall Plaza-ThanhNien St	Hai Duong	Mixed	No50	35x35	40
NP-M76	Hai Duong	North Plain		No206	35x35	40
NP-M77		-			35x35	40
NM-M78	Khu Du Lich NhaNghi-Chi Linh	Hai Duong	Mixed	No49	D=30	21.5
NM-M79	Hai Duong	North Plain			D=30	21.5
NM-M80		-			D=30	21.5
NP-M81	Nha Tap Luyen Da Nang	Hai Duong	Mixed	TN01	25x25	30.9
NP-M82	Hai Duong	North Plain		TN02	25x25	30.9

Table E-1 (cont.)

NP-M83	Tru So Lam Viec - Van An	Hai Duong	Mixed	TN01	20x20	8.2
NP-M84	Hai Duong	North Plain		TN02	20x20	8.2
NP-M85	BenhVienLaoPhoi	Hai Duong	Mixed	TN01	25x25	30
NP-M86	Hai Duong	North Plain		TN02	25x25	30
NP-M87	Nha Lam Viec Cong An-GiaLoc	Hai Duong	Mixed	TN01	25x25	18
NP-M88	Hai Duong	North Plain		TN02	25x25	18
NP-M89	Cam Phuc-Cam Giang	Hai Duong	Mixed	TN04	20x20	13.25
NP-M90	Hai Duong	North Plain		TN40	20x20	13.25
NP-M91	ngan hang congthuong	Hai Duong	Mixed	TN14	30x30	32.5
NP-M92	Hai Duong	North Plain		TN57	30x30	32.6
NP-M93		-		TN80	30x30	33.5
NP-M94	Ngan Hang BacHai Duong	Hai Duong	Mixed	TN-1	25x25	10
NP-M95	-	North Plain		TN-175	25x25	10
NP-M96	-	-		TN-186	25x25	10.2
NP-M97	Bo Chi HuyQuan Su Hai Duong	Hai Duong	Mixed	N44	25x25	12
NP-M98	-	North Plain		N108	25x25	12
NP-M99	Trung Tam Thuong Mai Van Hoa	HaiPhong	Mixed	C01	40x40	38
NP-M100	HaiPhong	North Plain		C02	40x40	38
NP-M101		-		C03	40x40	38
NP-M102		-		C04	40x40	38
NP-M103	TrungTrac-Van Lam-Hung Yen	Hung Yen	Mixed	TN31-C10	20x20	18
NP-M104		North Plain		TN137-A24	20x20	18
NP-M105		-		TN94-C31	20x20	18
NP-M106	So Tai Nguyen Moi Truong	Thai Binh	Mixed	NT1TB	35x35	4
NP-M107	Thai Binh	North Plain		TN02TB	35x35	4
NP-M108	-	-		TN03TB	35x35	4
CP-C1	Dong Hoi-QuangBinh	Quang	Clay	No162-A6	25x25	11
CP-C2		Binh		No242-F9	25x25	12
CP-C3		Central		No284-A10	25x25	11
CP-C4		Plain		No41-F3	25x25	10.4
CP-C5		-		No4-A1	25x25	11.4
CP-C6	Phan Chu Trinh-Da Lat-Lam Dong	Da Lat	Clay	No550	30x30	18
CP-C7		Central		No530	30x30	18
CP-C8		Mountain		No228	30x30	18
CP-C9		-		No31	30x30	18
CP-C10		-		No138	30x30	18
CP-C11	Tuongdai Le Loi-ThanhHoa	ThanhHoa	Clay	No1	30x30	16
CP-S1	Nha may dong tau Danang	Da Nang	Sand	TD1	40x40	34.1
CP-S2	-	Central Plain		TD2	40x40	31.8
CP-S3	-			TD3	40x40	33.6
CP-S4	-			TD4	40x40	31.5
CP-S5	-			TD5	40x40	30.6
CP-M1	Doosan	QuangNgai	Mixed	A-3-6 (TP1)	D=40	20.3
CP-M2	-	Central Plain		Y3-A33 (TP2)	D=40	25.6
CP-M3	-	-		RT 25 (TP3)	D=40	25.3
CP-M4	-	-		B-17-2 (TP4)	D=40	25.7
CP-M5	-	-		A20 (TP5)	D=40	26.4

Table E-1 (cont.)

CP-M6	-	-		Y4-12 (TP6)	D=40	22.7
CP-M7	-	-		Y2-1-D10 (TP7)	D=40	24.7
CP-M8	-	-		B-4-06 (TP8)	D=40	26
CP-M9	-	-		A-5-03 (TP9)	D=40	25.6
CP-M10	-	-		MF2.30 (TP10)	D=40	26.4
CP-M11	-	-		A-3-2 (TP11)	D=40	28
CP-M12	-	-		ST05 (TP12)	D=40	28.4
CP-M13	-	-		Y6-B14 (TP13)	D=40	24.7
CP-M14	-	-		Y5-12 (TP14)	D=40	24.3
CP-M15	-	-		Y7-B12 (TP15)	D=40	26.5
CP-M16	-	-		MF.Y1-J30 (TP16)	D=40	30.05
CP-M17	-	-		A-2-1 (TP17)	D=40	16.8
CP-M18	-	-		B-22	D=40	27.1
CP-M19	-	-		A-29	D=40	27.1
CP-M20	San bay -NhaGaHanhKhach	Da Nang Central	Mixed	N03(P1-480)	40x40	20.5
CP-M21	Danang	Plain		N04(P1-532)	40x40	23.85
CP-M22	-	-		N06(P2-57)	40x40	20.7
CP-M23	-	-		N07(P2-63)	40x40	20.92
CP-M24	-	-		N09(P3-159)	40x40	20.78
CP-M25	-	-		N10(P1-347)	40x40	22.32
CP-M26	-	-		N1(P1-151)	40x40	24.95
CP-M27	-	-		N2(P1-221)	40x40	26.25
CP-M28	-	-		N5(P2-3)	40x40	23.89
CP-M29	-	-		N8(P3-7)	40x40	24.15
CP-M30	-	-		N11(P3-411)	40x40	26.36
CP-M31	-	-		N12(P3-510)	40x40	25.1
CP-M32	-	-		N13(P5-8)	30x30	22.8
CP-M33	-	-		N14(P4-30)	30x30	26.1
CP-M34	PhongPhu-TP Hue	Hue Central	Mixed	D10-26	30x30	19
CP-M35		Plain		D5-458	30x30	20
CP-M36		-		T13-309	30x30	12
CP-M37		-		T12-290	30x30	12
CP-M38		-		C6-405	30x30	16
CP-M39		-		C8-144	30x30	16
CP-M40	TP Vinh- Nghe An	Nghe An Central	Mixed	N02	25x25	24
CP-M41		Plain		N03	25x25	24
CP-M42		-		N01-122	25x25	24
CP-M43		-		N02-23	25x25	24
CP-M44	Dung Quat	QuangNgai Central	Mixed	1-A-1-8	D=40	23
CP-M45	-	Plain		1-B-1-1	D=40	23.1
CP-M46	-	-		1-A-8-3	D=40	23.5
CP-M47	-	-		1-B-12-1	D=40	23.1

Table E-1 (cont.)

CP-M48	-	-		1-B-7-3	D=40	23
CP-M49	-	-		1-F-4-3	D=40	23.2
CP-M50	-	-		1-J-4-4	D=40	23
CP-M51	-	-		1-J-2-4	D=40	23.3
CP-M52	-	-		C-3-4	D=40	24
CP-M53	-	-		TP-A-17-3	D=40	24
SP-C1	CauPhu My-Saigon	SaiGon	Clay	No22	40x40	27.7
SP-C2	Cong tyximangHiepPhuoc-Saigon	SaiGon	Clay	No22	30x30	36
SP-M1	Tong KhoXangDauNha Be-Saigon	SaiGon	Mixed	N01-A33	30x30	41.8
SP-M2		South Plain		N02-A33	30x30	44.5
SP-M3		-		N03-A33	30x30	45
SP-M4		-		N04-A32	30x30	39
SP-M5		-		N05-A32	30x30	39
SP-M6		-		N06-A32	30x30	37
SP-M7		-		N10-A26	30x30	34
SP-M8		-		N11-A26	30x30	35.5
SP-M9		-		N12-A26	30x30	35
SP-M10	Intel-corp- Nut giao thong Thu Duc	SaiGon	Mixed	TP1	20x20	18
SP-M11	SaiGon	South Plain		TP2	20x20	18
SP-M12	-	-		TP3	20x20	18
SP-M13	-	-		TP4	20x20	18
SP-M14	-	-		TP5	D=30	24
SP-M15	-	-		TP6	D=30	24
SP-M16	-	-		TP7	D=40	22
SP-M17	UngThanhHao Mon -Phuong 7-Q8	SaiGon	Mixed	N01-CD1	40x40	43.6
SP-M18	Saigon	South Plain		N02-CD2	40x40	43.8
SP-M19	ASU-Phu My-Ba Ria-Vung Tau	Vung Tau	Mixed	N01-L129-P2	30x30	8.3
SP-M20	SaiGon	South Plain		N02-L4-P1	30x30	8.35
SP-M21	-	-		N03-L14-P2	30x30	12.3
SP-M22	-	-		N04-L33-P1	30x30	9.05
SP-M23	Nha May Su lyNuoc Thai - SaiGon	SaiGon	Mixed	BLB-TP1	40x40	41,77
SP-M24	-	South Plain	Mixed	LP-TP1	40x40	40,19
SP-M25	-	-	Mixed	FB-TP2	40x40	39,3
SP-M26	-	-	Mixed	WTF-TP1	40x40	42,15
SP-M27	-	-	Mixed	DDS-TP1	40x40	38,86
SP-M28	-	-	Mixed	T1-TP1	40x40	38,8
SP-S1	Nha May Su lyNuoc Thai - Sai Gon	-	Sand	WTF-TP3	40x40	39,47
SP-S2		-	Sand	WTF-TP4	40x40	39,45
SP-S3	-	-	Sand	LP-TP2	40x40	40,1
SP-S4	-	-	Sand	1FB-TP1	40x40	39,54

Table E-2 Summary measure capacity of driven pile from North, Central and South of Vietnam by different criterion

No	Chin's Method	80% Chin's Method	Davision's method	1"
NP-C1	71.4	57.1	28.8	46.0
NP-C2	58.8	47.1	33.6	44.0
NP-C3	120.5	96.4	94.0	98.0
NP-C4	109.9	87.9	82.5	90.0
NP-C5	125.0	100.0	97.0	101.0
NP-C6	122.0	97.6	96.0	100.0
NP-C7	84.7	67.8	72.0	76.0
NP-C8	243.9	195.1	158.0	149.6
NP-C9	250.0	200.0	165.2	152.8
NP-C10	188.7	150.9	131.4	133.0
NP-C11	217.4	173.9	147.0	140.2
NP-C12	172.4	137.9	133.0	133.0
NP-C13	232.6	186.0	156.7	150.0
NP-C14	89.3	71.4	55.0	68.0
NP-C15	79.4	63.5	32.0	50.0
NP-C16	78.7	63.0	50.0	62.5
NP-C17	30.1	24.1	20.0	20.0
NP-C18	29.9	23.9	21.0	21.0
NP-C19	30.3	24.2	18.0	17.8
NP-C20	30.6	24.5	17.5	17.5
NP-C21	116.3	93.0	77.0	94.3
NP-C22	149.3	119.4	113.0	115.0
NP-C23	104.2	83.3	59.0	70.0
NM-C24	133.3	106.7	112.5	121.9
NM-C25	149.3	119.4	119.0	129.5
NM-C26	153.8	153.8	153.8	153.8
NM-C27	153.8	123.1	119.0	129.5
NM-C28	147.1	117.6	117.0	125.0
NM-C29	119.0	95.2	99.0	106.0
NM-C30	119.0	95.2	103.3	109.0
NM-C31	131.6	105.3	115.0	120.0
NM-C32	*144.9*	*115.9*	*117.0*	*126.0*
NM-C33	169.5	135.6	75.0	105.0
NM-C34	48.8	39.0	22.0	36.0
NM-C35	105.3	84.2	60.0	83.0
NM-C36	142.9	114.3	66.0	97.0
NM-C37	109.9	87.9	68.0	86.0
NM-C38	104.2	83.3	68.0	84.0
NP-S1	54.3	43.5	46.0	49.5
NP-S2	52.9	42.3	45.0	47.5
NP-S3	59.5	47.6	52.5	54.0
NP-S4	131.6	105.3	112.5	116.7
NP-S5	135.1	108.1	116.1	119.5
NP-S6	125.0	100.0	105.9	110.0
NP-S7	140.8	112.7	118.0	122.0

Table E-2 (cont.)

NP-S8	133.3	106.7	114.3	117.6
NP-S9	137.0	109.6	112.5	115.5
NP-S10	135.1	108.1	115.3	118.8
NP-S11	128.2	102.6	115.3	118.8
NP-S12	119.0	95.2	103.2	107.2
NP-S13	131.6	105.3	112.5	116.7
NP-S14	126.6	101.3	109.7	113.4
NP-S15	135.1	108.1	116.5	119.8
NP-S16	126.6	101.3	112.5	114.1
NP-S17	129.9	103.9	112.5	115.4
NP-S18	131.6	105.3	108.8	113.5
NP-S19	125.0	100.0	105.4	109.5
NP-S20	101.0	80.8	85.3	88.0
NP-S21	133.3	106.7	100.0	102.0
NP-S22	147.1	117.6	111.8	112.0
NP-S23	85.5	68.4	74.0	76.2
NP-S24	97.1	77.7	83.1	85.5
NP-S25	129.9	103.9	95.0	98.3
NP-S26	136.99	109.6	120.0	120.0
NP-S27	105.3	84.2	90.4	92.5
NP-S28	117.6	94.1	99.3	100.5
NP-S29	102.0	81.6	87.0	89.0
NP-S30	126.6	101.3	99.7	101.5
NP-S31	96.2	76.9	79.8	83.2
NP-S32	500.0	400.0	410.0	356.0
NP-S33	416.7	333.3	337.4	305.0
NP-S34	312.5	250.0	279.0	270.0
NP-S35	81.3	65.0	65.0	68.0
NP-S36	85.5	68.4	72.0	75.0
NP-S37	73.5	58.8	65.0	67.0
NP-S38	76.3	61.1	59.0	60.0
NP-S39	84.0	67.2	58.0	60.0
NP-S40	60.2	48.2	36.5	48.8
NP-S41	48.8	39.0	40.1	45.5
NP-S42	46.7	37.4	39.6	44.3
NP-S43	46.5	37.2	40.0	43.9
NP-S44	60.6	48.5	45.0	52.0
NP-S45	60.2	48.2	45.0	52.0
NP-S46	103.1	82.5	52.5	69.0
NP-S47	277.8	222.2	155.0	155.0
NP-S48	208.3	166.7	145.0	145.0
NP-S49	163.9	131.1	133.0	133.0
NP-S50	161.3	129.0	114.0	114.0
NP-S51	83.3	66.7	42.0	60.0
NP-S52	57.5	46.0	40.0	50.0
NP-S53	76.9	61.5	47.5	61.7
NP-S54	80.0	64.0	49.0	62.0
NP-M1	172.4	137.9	158.0	156.0
NP-M2	227.3	181.8	179.0	184.0

Table E-2 (cont.)

NP-M3	270.3	216.2	110.0	142.0
NP-M4	192.3	153.8	137.5	152.3
NP-M5	222.2	177.8	137.5	155.6
NP-M6	370.4	296.3	255.0	245.0
NP-M7	344.8	275.9	275.0	260.0
NP-M8	370.4	296.3	285.0	265.0
NP-M9	344.8	275.9	239.0	233.0
NP-M10	186.2	149.0	140.0	140.0
NP-M11	175.4	140.4	138.0	145.0
NP-M12	175.4	140.4	137.0	145.0
NP-M13	178.6	142.9	139.0	147.0
NP-M14	175.4	140.4	138.0	145.0
NP-M15	175.4	140.4	138.0	145.0
NP-M16	172.4	137.9	136.0	144.0
NP-M17	158.7	127.0	133.0	139.0
NP-M18	147.1	117.6	115.0	111.2
NP-M19	137.0	109.6	101.5	103
NP-M20	166.7	133.3	120.0	113.0
NP-M21	129.9	103.9	99.5	98.5
NP-M22	158.7	127.0	105.0	103.0
NP-M23	153.8	123.1	101.5	105.5
NP-M24	59.5	47.6	42.0	50.0
NP-M25	41.3	33.1	35.0	38.3
NP-M26	238.1	190.5	180.0	184.5
NP-M27	238.1	190.5	169.0	182.0
NP-M28	243.9	195.1	183.0	192.5
NP-M29	243.9	195.1	203.0	209.0
NP-M30	250.0	200.0	196.0	203.5
NP-M31	204.1	163.3	140.6	152.0
NP-M32	212.8	170.2	149.2	158.7
NP-M33	181.8	145.5	127.0	138.8
NP-M34	227.3	186.0	142.0	155.7
NP-M35	166.7	133.3	127.5	136.5
NP-M36	131.6	105.3	110.6	117.4
NP-M41	476.2	381.0	327.6	375.0
NP-M42	434.8	347.8	342.0	310.0
NP-M43	454.5	363.6	310.0	278.0
NP-M44	312.5	250.0	284.0	276.8
NP-M45	322.6	258.1	267.0	256.4
NP-M46	107.5	86.0	60.0	80.0
NP-M47	74.6	59.7	48.0	61.0
NP-M48	149.3	119.4	69.0	97.0
NP-M49	84.7	67.8	56.0	70.0
NP-M50	120.5	96.4	64.0	87.0
NP-M51	69.9	55.9	50.0	60.0
NP-M52	65.4	52.3	48.0	57.4
NP-M53	77.5	62.0	57.0	66.0
NP-M54	185.2	148.1	133.4	141.5
NP-M55	178.6	142.9	134.0	141.5

Table E-2 (cont.)

NP-M56	181.8	145.5	139.5	146.5
NP-M57	161.3	129.0	133.0	138.0
NP-M58	108.6	86.9	78.0	89.0
NP-M59	83.1	66.5	70.0	76.0
NP-M60	100.4	80.3	76.0	85.0
NP-M61	277.8	222.2	187.0	158.0
NP-M62	277.8	222.2	161.9	140.0
NP-M63	53.8	43.0	30.0	41.7
NP-M64	38.5	30.8	26.0	33.0
NP-M65	43.7	34.9	24.0	34.4
NP-M66	51.8	41.5	38.0	45.0
NP-M67	59.9	47.9	42.0	50.0
NP-M68	111.1	88.9	70.0	76.0
NP-M69	142.9	114.3	80.0	84.0
NP-M70	142.9	114.3	80.0	84.0
NP-M71	147.1	117.6	109.0	102.0
NP-M72	92.6	74.1	80.0	80.0
NP-M73	108.7	87.0	78.0	84.0
NP-M74	117.6	94.1	78.0	92.0
NP-M75	357.1	285.7	231.0	190.5
NP-M76	344.8	275.9	266.0	225.0
NP-M77	357.1	285.7	236.0	200.0
NM-M78	186.6	149.3	132.0	135.0
NM-M79				
NM-M80				
NP-M81	96.2	76.9	65.0	75.0
NP-M82	109.9	87.9	72.0	82.0
NP-M83	68.5	54.8	26.0	43.0
NP-M84	78.1	62.5	27.0	49.0
NP-M85	78.1	62.5	50.0	58.0
NP-M86	90.9	72.7	57.0	64.0
NP-M87	104.2	83.3	68.0	80.0
NP-M88	117.6	94.1	70.0	85.0
NP-M89	33.8	27.0	18.0	26.3
NP-M90	36.9	29.5	20.0	28.3
NP-M91	111.1	88.9	90.0	93.6
NP-M92	112.4	89.9	90.0	93.3
NP-M93	111.1	88.9	90.0	93.3
NP-M94	126.6	101.3	78.0	99.0
NP-M95	114.9	92.0	76.0	93.5
NP-M96	116.3	93.0	77.0	94.3
NP-M97	106.4	85.1	45.0	61.2
NP-M98	79.4	63.5	45.0	61.2
NP-M99	217.4	173.9	192.0	192.0
NP-M100				
NP-M101				
NP-M102	172.4	137.9	158.0	158.0
NP-M103	74.6	59.7	62.5	65.5

Table E-2 (cont.)

NP-M104	64.9	51.9	57.0	59.0
NP-M105	103.6	82.9	76.0	80.0
NP-M106	222.2	177.8	172.0	162.0
NP-M107	175.4	140.4	147.0	144.0
NP-M108	212.8	170.2	164.8	157.0
CP-C1	129.9	103.9	90.0	116.0
CP-C2	144.5	115.6	100.0	116.0
CP-C3	163.9	131.1	122.0	138.0
CP-C4	129.9	103.9	95.0	115.0
CP-C5	151.5	121.2	120.0	127.0
CP-C6	181.8	145.5	126.0	126.0
CP-C7	370.4	296.3	213.0	214.0
CP-C8	227.3	181.8	168.0	175.0
CP-C9	285.7	228.6	213.0	215.0
CP-C10	312.5	250.0	196.0	202.0
CP-S1	152.0	152.0	152.0	152.0
CP-S2	231.2	231.2	231.2	231.2
CP-S3	144.5	144.5	144.5	144.5
CP-S4	249.6	249.6	249.6	249.6
CP-S5	157.2	157.2	157.2	157.2
CP-M1	217.4	173.9	180.0	190.0
CP-M2	250.0	200.0	210.0	210.8
CP-M3	312.5	250.0	260.0	254.0
CP-M4	227.3	181.8	188.0	191.0
CP-M5	434.8	347.8	255.0	257.0
CP-M6	238.1	190.5	205.0	208.0
CP-M7	357.1	285.7	277.0	227.0
CP-M8	217.4	173.9	180.0	187.5
CP-M9	303.0	242.4	231.0	227.0
CP-M10	344.8	275.9	280.0	267.0
CP-M11	175.4	140.4	162.0	165.5
CP-M12	344.8	275.9	283.0	283.0
CP-M13	277.8	222.2	226.0	226.8
CP-M14	200.0	160.0	168.8	175.7
CP-M15	357.1	285.7	227.0	227.0
CP-M16	333.3	266.7	284.0	268.0
CP-M17	227.3	181.8	187.5	202.1
CP-M20	416.7	333.3	260.0	274.5
CP-M21	370.4	296.3	269.0	272.0
CP-M22	384.6	307.7	260.0	270.5
CP-M23	344.8	275.9	260.0	266.5
CP-M24	434.8	347.8	255.0	266.5
CP-M25	555.6	444.4	304.5	309.8
CP-M26	416.7	333.3	260.0	274.5
CP-M27	476.2	381.0	273.0	273.0
CP-M28	476.2	381.0	273.0	273.0
CP-M29	416.7	333.3	260.0	274.5
CP-M30	434.8	347.8	250.0	258.0
CP-M31	370.4	296.3	269.0	272.0

Table E-2 (cont.)

CP-M32	270.3	216.2	224.0	216.0
CP-M33	294.1	235.3	172.3	173.0
CP-M34	285.7	188.0	160.0	175.0
CP-M35	158.7	127.0	154.5	155.1
CP-M36	196.1	156.9	125.4	148.5
CP-M37	196.1	156.9	125.4	148.5
CP-M38	196.1	156.9	122.0	142.0
CP-M39	232.6	186.0	113.0	142.0
CP-M40	133.3	106.7	94.0	98.0
CP-M41	139.7	111.7	94.0	98.0
CP-M42	126.6	101.3	100.0	102.0
CP-M43	114.5	91.6	86.0	91.0
SP-C1	363.6	290.9	253.0	253.0
SP-C2	100.0	80.0	76.0	79.0
SP-M1	200.0	160.0	141.0	133.0
SP-M2	192.3	153.8	113.0	124.2
SP-M3	217.4	173.9	142.0	164.5
SP-M4	140.8	112.7	105.0	104.0
SP-M5	138.9	111.1	119.0	120.0
SP-M6	196.1	156.9	142.0	133.0
SP-M7	196.1	156.9	134.5	140.0
SP-M8	208.3	166.7	144.5	155.0
SP-M9	169.5	135.6	130.0	126.3
SP-M10	106.4	85.1	82.5	85.7
SP-M11	113.6	90.9	90.0	91.3
SP-M12	116.3	93.0	93.0	95.0
SP-M13				
SP-M14	133.3	106.7	100.0	100.0
SP-M15				
SP-M16	300.3	240.2	245.0	250.0
SP-M17	526.3	421.1	445.0	350.0
SP-M18	769.2	615.4	618.0	410.0
SP-M19	157.7	126.2	132.0	144.1
SP-M20	157.8	126.3	128.0	142.6
SP-M21	193.5	154.8	150.0	170.0
SP-M22	191.5	153.2	110.0	150.0
SP-M23	178.6	142.9	151.5	153.0
SP-M24	270.3	216.2	194.5	188.5
SP-M25	200.0	160.0	162.3	164.0
SP-M26	232.6	186.0	189.5	186.0
SP-M27	158.7	127.0	141.0	143.7
SP-M28	192.3	153.8	156.0	160.0
SP-S1	232.6	186.0	180.5	181.8
SP-S2	227.3	181.8	165.5	167.5
SP-S3	158.7	127.0	141.0	143.7
SP-S4	192.3	153.8	151.0	153.6

Table E-3 Summary nominal capacity of driven pile in Cohesionless Soil from North, Central and South of Vietnam by different method

	Nordlund		SPT	
	ΦPeck, Hanson and Thornburn	Φ from Schmertmann	Schmertmann SPT	Mayhoft SPT
	Q1	Q2	Q3	Q4
NP-S1	57.35	93.23	51.98	49.12
NP-S2	60.36	98.14	54.71	51.71
NP-S3	63.38	103.05	57.45	54.29
NP-S4	176.29	277.69	137.14	142.88
NP-S5	174.66	275.12	135.88	141.56
NP-S6	173.03	272.55	134.61	140.24
NP-S7	171.40	269.98	133.34	138.91
NP-S8	169.76	267.41	132.07	137.59
NP-S9	168.13	264.84	130.80	136.27
NP-S10	166.50	262.27	129.53	134.94
NP-S11	164.87	259.70	128.26	133.62
NP-S12	163.23	257.12	126.99	132.30
NP-S13	161.60	254.55	125.72	130.97
NP-S14	159.97	251.98	124.45	129.65
NP-S15	158.34	249.41	123.18	128.33
NP-S16	156.70	246.84	121.91	127.01
NP-S17	155.07	244.27	120.64	125.68
NP-S18	153.44	241.70	119.37	124.36
NP-S19	151.81	239.13	118.10	123.04
NP-S20	150.63	221.42	92.45	90.63
NP-S21	149.20	219.31	91.57	89.77
NP-S22	147.76	217.20	90.69	88.90
NP-S23	146.33	215.09	89.80	88.04
NP-S24	144.90	212.98	88.92	87.18
NP-S25	143.46	210.87	88.04	86.32
NP-S26	142.03	208.77	87.16	85.45
NP-S27	140.59	206.66	86.28	84.59
NP-S28	139.16	204.55	85.40	83.73
NP-S29	137.72	202.44	84.52	82.86
NP-S30	136.29	200.33	83.64	82.00
NP-S31	134.85	198.22	82.76	81.14
NP-S32	671.00	1193.34	339.84	288.08
NP-S33	639.05	1136.52	323.66	274.36
NP-S34	607.10	1079.69	307.48	260.64
NP-S35	58.78	162.05	59.34	63.25
NP-S36	56.11	154.68	56.64	60.38
NP-S37	53.44	147.32	53.94	57.50
NP-S38	50.77	139.95	51.25	54.63
NP-S39	48.10	132.59	48.55	51.75
NP-S40	53.44	53.45	31.86	35.11
NP-S41	35.35	63.65	49.28	61.33

Table E-3 (cont.)

NP-S42	34.48	62.10	48.08	59.84
NP-S43	33.62	60.55	46.88	58.34
NP-S44	29.93	60.07	25.01	23.15
NP-S45	33.26	66.75	27.79	25.72
NP-S46	36.59	73.42	30.57	28.30
NP-S47	198.48	237.84	84.90	72.28
NP-S48	180.43	216.22	77.18	65.71
NP-S49	171.41	205.41	73.32	62.42
NP-S50	162.39	194.60	69.46	59.14
NP-S51	37.78	59.52	39.85	42.50
NP-S52	34.00	53.56	35.87	38.25
NP-S53	37.78	59.52	39.85	42.50
NP-S54	41.56	65.47	43.84	46.75
SP-S1	237.60	313.25	133.41	100.32
SP-S2	195.97	296.99	116.55	79.27
SP-S3	244.11	369.42	127.89	137.86
SP-S4	327.44	507.40	172.37	167.21

Table E-4 Summary nominal capacity of driven pile in Cohesive Soil from North, Central and South of Vietnam by different method

	Data from North, Central and South of Vietnam							
	α-Tomlinson method		α-API method		λ method		β-Burland method	Schmertmann SPT
	Su-Terzaghi, Peck	Su-Hara	Su-Terzaghi, Peck	Su-Hara	Su-Terzaghi, Peck	Su- Hara		
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
NP-C1	35.8	71.6	22.5	46.3	28.4	58.4	21.6	38.3
NP-C2	32.5	65.1	20.5	42.1	25.8	53.1	19.6	34.8
NP-C3	88.2	166.8	68.2	122.5	67.3	124.1	74.3	101.9
NP-C4	84.2	159.2	65.1	116.9	64.3	118.5	70.9	97.3
NP-C5	80.2	151.6	62.0	111.4	61.2	112.8	67.5	92.7
NP-C6	76.2	144.0	58.9	105.8	58.1	107.2	64.2	88.0
NP-C7	72.1	136.4	55.8	100.2	55.1	101.6	60.8	83.4
NP-C8	144.6	196.9	116.8	175.2	106.5	159.6	147.4	130.5
NP-C9	152.6	207.8	123.3	184.9	112.5	168.5	155.6	137.8
NP-C10	160.7	218.8	129.8	194.6	118.4	177.3	163.8	145.0
NP-C11	176.7	240.6	142.8	214.1	130.2	195.1	180.2	159.5
NP-C12	168.7	229.7	136.3	204.4	124.3	186.2	172.0	152.3
NP-C13	184.8	251.6	149.3	223.8	136.1	203.9	188.4	166.8
NP-C14	53.6	71.6	40.2	71.2	45.4	86.4	48.4	59.3
NP-C15	51.0	68.2	38.3	67.8	43.2	82.3	46.1	56.5
NP-C16	48.5	64.8	36.4	64.5	41.1	78.2	43.8	53.6
NP-C17	15.9	23.6	11.4	24.7	14.8	30.5	13.5	20.6
NP-C18	17.5	26.0	12.5	27.2	16.3	33.6	14.9	22.7
NP-C19	17.9	25.5	12.5	26.2	15.9	32.2	13.5	22.1
NP-C20	19.6	28.1	13.8	28.8	17.5	35.4	14.9	24.3
NP-C21	115.5	152.9	56.6	182.1	96.3	173.0	123.8	121.5
NP-C22	109.7	145.2	53.8	172.9	91.5	164.4	117.6	115.5
NP-C23	77.9	79.2	78.3	89.6	74.6	82.1	89.6	55.8
NM-C24	76.5	133.0	51.8	95.7	71.4	129.7	66.8	88.0
NM-C25	80.7	140.4	54.7	101.0	75.4	136.9	70.5	92.9
NM-C26	93.5	162.5	63.3	116.9	87.3	158.5	81.7	107.6
NM-C27	85.0	147.7	57.5	106.3	79.3	144.1	74.2	97.8
NM-C28	106.6	143.0	67.8	216.2	136.6	234.3	137.2	155.8
NM-C29	112.5	151.0	71.5	228.2	144.1	247.3	144.8	164.5
NM-C30	118.5	158.9	75.3	240.2	151.7	260.3	152.4	173.1
NM-C31	124.4	166.9	79.1	252.2	159.3	273.4	160.1	181.8
NM-C32	130.3	174.8	82.8	264.2	166.9	286.4	167.7	190.5
NM-C33	50.6	79.9	40.4	66.2	47.8	82.2	41.5	85.5
NM-C34	47.9	75.7	38.2	62.7	45.3	77.9	39.4	81.0
NM-C35	53.3	84.1	42.5	69.7	50.4	86.6	43.7	90.0
NM-C36	55.9	88.3	44.6	73.2	52.9	90.9	45.9	94.5
NM-C37	58.6	92.5	46.7	76.6	55.4	95.2	48.1	99.0
NM-C38	61.2	96.7	48.9	80.1	57.9	99.5	50.3	103.5
CP-C1	36.7	67.6	48.9	79.2	55.0	96.9	36.8	83.9
CP-C2	37.7	69.4	50.2	81.2	56.4	99.4	37.8	86.1
CP-C3	38.7	71.2	51.5	83.3	57.9	102.0	38.7	88.3
CP-C4	39.6	72.9	52.8	85.4	59.3	104.5	39.7	90.5
CP-C5	40.6	74.7	54.1	87.5	60.8	107.1	40.7	92.7

Table E-4 (cont.)

CP-C6	153.3	151.4	87.0	162.6	91.1	176.4	89.1	127.4
CP-C7	157.3	155.4	89.3	166.9	93.5	181.1	91.5	130.7
CP-C8	161.4	159.3	91.6	171.2	95.9	185.7	93.8	134.1
CP-C9	165.4	163.3	93.9	175.4	98.3	190.4	96.2	137.4
CP-C10	169.4	167.3	96.2	179.7	100.7	195.0	98.5	140.8
CP-C11								
SP-C1	167.9	286.7	150.2	244.3	140.2	233.5	176.0	195.1
SP-C2	106.5	111.8	129.7	175.5	116.1	177.0	168.6	70.3

Table E-5 Summary nominal capacity of driven pile in MixedSoil from North, Central and South of Vietnam by different method

	Data from North, Central and South of Vietnam														
	Φ from Peck, Hanson and Thornburn							Φ from Schmertmann							
	α-Tomlinson/Nordlund		α-API /Nordlund		λ /Nordlund		β Burland/ Nordlund	α-Tomlinson/Nordlund		α-API / Nordlund		λ /Nordlund		β Burland/ Nordlund	Schmertmann SPT
	Su-Terzaghi Peck	Su-Hara	Su-Terzaghi, Peck	Su-Hara	Su-Terzaghi, Peck	Su-Hara		Su-Terzaghi Peck	Su-Hara	Su-Terzaghi, Peck	Su-Hara	Su-Terzaghi, Peck	Su- Hara		
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q11	Q14	Q15
NP-M1	218.3	236.4	178.9	267.2	180.5	269.7	203.6	271.2	289.3	231.8	320.1	144.0	322.6	256.5	153.7
NP-M2	241.3	261.3	197.7	295.3	199.5	298.0	225.0	299.8	319.8	256.2	353.8	159.2	356.5	283.5	169.9
NP-M3	146.9	190.9	138.2	154.7	138.6	157.1	137.6	115.8	320.2	267.5	284.0	267.9	286.4	266.9	142.1
NP-M4	154.6	201.0	145.5	162.8	145.9	165.4	144.9	121.9	337.1	281.6	298.9	282.0	301.5	280.9	149.6
NP-M5	162.3	211.0	152.8	171.0	153.2	173.7	152.1	128.0	353.9	295.6	313.9	296.1	316.5	295.0	157.1
NP-M6	213.1	361.2	210.7	278.1	201.1	258.3	260.6	314.0	462.1	311.7	379.0	302.1	359.2	361.5	162.5
NP-M7	207.5	351.7	205.2	270.7	195.9	251.5	253.7	305.8	450.0	303.5	369.0	294.1	349.7	352.0	158.2
NP-M8	224.3	380.2	221.8	292.7	211.7	271.9	274.3	330.6	486.5	328.1	398.9	318.0	378.1	380.5	171.1
NP-M9	229.9	389.7	227.4	300.0	217.0	278.7	281.1	338.8	498.6	336.3	408.9	325.9	387.6	390.0	175.4
NP-M11	144.6	153.0	129.3	149.0	127.6	149.1	134.8	227.9	236.4	212.6	232.3	211.0	232.4	218.2	119.9
NP-M12	148.5	157.1	132.8	153.0	131.1	153.1	138.5	234.1	242.7	218.4	238.6	216.7	238.7	224.1	123.1
NP-M13	152.4	161.3	136.3	157.0	134.5	157.1	142.1	240.3	249.1	224.1	244.9	222.4	245.0	230.0	126.4
NP-M14	156.3	165.4	139.7	161.0	138.0	161.1	145.7	246.4	255.5	229.9	251.2	228.1	251.3	235.9	129.6
NP-M15	160.2	169.5	143.2	165.1	141.4	165.2	149.4	252.6	261.9	235.6	257.4	233.8	257.6	241.8	132.8
NP-M16	164.1	173.7	146.7	169.1	144.9	169.2	153.0	258.7	268.3	241.4	263.7	239.5	263.8	247.7	136.1
NP-M17	168.0	177.8	150.2	173.1	148.3	173.2	156.7	264.9	274.7	247.1	270.0	245.2	270.1	253.6	139.3
NP-M18	89.5	102.2	71.8	93.5	65.7	86.1	78.6	124.7	137.4	106.9	128.6	105.9	121.2	103.4	82.9
NP-M19	94.5	107.8	75.8	98.7	69.4	90.8	83.0	131.6	145.0	112.9	135.8	111.8	128.0	109.2	87.5
NP-M20	99.5	113.5	79.7	103.8	73.1	95.6	87.3	138.6	152.6	118.8	142.9	117.7	134.7	114.9	92.1
NP-M21	104.5	119.2	83.7	109.0	76.7	100.4	91.7	145.5	160.2	124.8	150.1	123.6	141.4	120.7	96.7
NP-M22	109.4	124.9	87.7	114.2	80.4	105.2	96.1	152.4	167.9	130.7	157.2	129.5	148.2	126.4	101.3
NP-M23	112.4	128.3	90.1	117.3	82.6	108.1	98.7	156.6	172.5	134.3	161.5	133.0	152.2	129.9	104.0
NP-M24	33.9	42.2	28.5	33.3	29.3	34.8	27.6	42.6	50.9	37.2	42.0	34.0	43.5	36.3	38.5
NP-M25	30.6	38.0	25.6	30.0	26.4	31.4	24.9	38.4	45.8	33.4	37.8	30.6	39.2	32.7	34.6
NP-M26	182.1	178.6	128.7	231.1	130.9	240.7	137.3	182.1	178.6	128.7	231.1	130.9	240.7	137.3	191.7
NP-M27	192.2	188.5	135.9	243.9	138.2	254.0	144.9	192.2	188.5	135.9	243.9	138.2	254.0	144.9	202.4

Table E-5 (cont.)

NP-M28	202.3	198.4	143.0	256.8	145.5	267.4	152.5	202.3	198.4	143.0	256.8	145.5	267.4	152.5	213.1
NP-M29	212.4	208.3	150.2	269.6	152.7	280.8	160.1	212.4	208.3	150.2	269.6	152.7	280.8	160.1	223.7
NP-M30	222.5	218.3	157.3	282.4	160.0	294.1	167.8	222.5	218.3	157.3	282.4	160.0	294.1	167.8	234.4
NP-M31	330.8	374.4	314.5	340.5	312.4	338.0	320.0	381.1	424.7	364.8	390.8	362.7	388.3	370.2	183.0
NP-M32	323.0	365.5	307.0	332.4	305.0	330.0	312.3	372.0	414.6	356.1	381.5	354.0	379.0	361.4	178.6
NP-M33	315.1	356.6	299.6	324.3	297.5	321.9	304.7	362.9	404.4	347.4	372.2	345.4	369.8	352.6	174.3
NP-M34	307.2	347.7	292.1	316.2	290.1	313.9	297.1	353.9	394.3	338.7	362.9	336.7	360.5	343.8	169.9
NP-M35	299.3	338.8	284.6	308.1	282.7	305.8	289.5	344.8	384.2	330.0	353.6	328.1	351.3	334.9	165.6
NP-M36	291.5	329.8	277.1	300.0	275.2	297.8	281.9	335.7	374.1	321.4	344.3	319.5	342.0	326.1	161.2
NP-M41	685.6	681.7	680.3	707.8	668.6	691.2	689.6	1096.1	1092.3	1090.9	1118.4	1079.2	1101.7	1100.2	305.9
NP-M42	623.2	619.8	618.5	643.4	607.8	628.3	626.9	996.5	993.0	991.7	1016.7	981.1	1001.6	1000.2	278.1
NP-M43	560.9	557.8	556.6	579.1	547.0	565.5	564.2	896.8	893.7	892.6	915.0	883.0	901.4	900.2	250.3
NP-M44	529.7	526.8	525.7	546.9	516.6	534.1	532.9	847.0	844.1	843.0	864.2	833.9	851.4	850.2	236.4
NP-M45	498.6	495.8	494.8	514.7	486.3	502.7	501.5	797.2	794.4	793.4	813.4	784.9	801.3	800.1	222.5
NP-M46	64.9	77.5	49.6	67.3	54.7	79.9	51.0	94.8	107.4	79.4	97.2	84.6	109.8	80.9	57.2
NP-M47	66.6	79.6	50.9	69.1	56.2	82.0	52.4	97.3	110.3	81.6	99.8	86.9	112.7	83.1	58.8
NP-M48	68.4	81.7	52.3	70.9	57.6	84.2	53.8	99.9	113.2	83.7	102.4	89.1	115.7	85.3	60.3
NP-M49	70.1	83.8	53.6	72.7	59.1	86.4	55.2	102.4	116.1	85.9	105.0	91.4	118.7	87.5	61.8
NP-M50	71.9	85.8	54.9	74.6	60.6	88.5	56.5	105.0	119.0	88.0	107.7	93.7	121.6	89.6	63.4
NP-M51	73.6	87.9	56.3	76.4	62.1	90.7	57.9	107.6	121.9	90.2	110.3	96.0	124.6	91.8	64.9
NP-M52	75.4	90.0	57.6	78.2	63.6	92.8	59.3	110.1	124.8	92.3	112.9	98.3	127.6	94.0	66.5
NP-M53	55.4	79.1	46.5	56.4	46.9	59.1	44.7	73.8	76.2	64.8	74.7	65.3	77.5	63.1	45.2
NP-M54	110.8	169.8	98.3	125.2	100.6	128.7	111.4	146.6	205.7	134.1	161.1	136.5	164.5	147.3	86.1
NP-M55	120.0	179.4	107.2	134.2	101.5	122.5	119.7	147.6	207.0	134.8	161.8	129.1	150.1	147.3	93.2
NP-M56	231.2	262.7	205.9	232.3	206.5	238.7	201.6	266.9	298.5	241.7	268.1	242.2	274.5	237.3	130.2
NP-M57	211.3	229.8	192.9	208.2	193.9	213.6	186.1	268.5	286.9	250.1	265.4	251.0	270.8	243.3	134.0
NP-M58	56.5	56.3	50.3	58.2	50.7	59.5	50.9	104.2	103.9	98.0	105.9	98.4	107.1	98.5	75.1
NP-M59	62.8	62.5	55.9	64.7	56.3	66.1	56.5	115.7	115.5	108.8	117.6	109.3	119.0	109.5	83.4
NP-M60	69.1	68.8	61.5	71.1	62.0	72.7	62.2	127.3	127.0	119.7	129.4	120.2	130.9	120.4	91.7
NP-M61	150.6	150.6	150.6	150.6	150.6	150.6	150.6	198.4	198.4	198.4	198.4	198.4	198.4	198.4	77.5
NP-M62	136.9	136.9	136.9	136.9	136.9	136.9	136.9	180.4	180.4	180.4	180.4	180.4	180.4	180.4	70.5
NP-M63	41.9	45.7	36.5	41.2	38.0	45.8	34.7	39.8	43.6	34.4	39.1	35.9	43.7	32.6	37.1
NP-M64	38.1	41.5	33.2	37.4	34.5	41.6	31.6	36.2	39.6	31.3	35.5	32.6	39.7	29.7	33.8
NP-M65	34.3	37.4	29.9	33.7	31.1	37.4	28.4	32.6	35.7	28.2	32.0	29.4	35.7	26.7	30.4
NP-M66	31.9	31.9	31.9	31.9	31.9	31.9	31.9	43.3	43.3	43.3	43.3	43.3	43.3	43.3	26.1
NP-M67	35.3	35.3	35.3	35.3	35.3	35.3	35.3	47.9	47.9	47.9	47.9	47.9	47.9	47.9	28.8

Table E-5 (cont.)

NP-M68	113.1	113.1	113.1	113.1	113.1	113.1	113.1	152.7	152.7	152.7	152.7	152.7	152.7	152.7	69.7
NP-M69	119.1	119.1	119.1	119.1	119.1	119.1	119.1	160.7	160.7	160.7	160.7	160.7	160.7	160.7	73.3
NP-M70	125.0	125.0	125.0	125.0	125.0	125.0	125.0	168.8	168.8	168.8	168.8	168.8	168.8	168.8	77.0
NP-M71	117.8	191.3	88.2	88.2	68.1	113.1	111.0	114.5	183.0	84.9	152.7	64.8	104.8	107.7	92.4
NP-M72	120.9	196.3	90.5	90.6	69.8	116.1	113.9	117.5	187.8	87.1	156.7	66.5	107.6	110.6	94.9
NP-M73	124.0	201.3	92.8	92.9	71.6	119.0	116.9	120.5	192.6	89.4	160.7	68.2	110.3	113.4	97.3
NP-M74	130.2	211.4	97.4	97.5	75.2	125.0	122.7	126.6	202.2	93.8	168.8	71.6	115.8	119.1	102.2
NP-M75	300.3	288.2	287.9	364.7	256.7	313.9	384.8	363.3	351.2	350.9	427.7	319.7	376.9	447.8	178.3
NP-M76	316.1	303.4	303.1	383.9	270.2	330.4	405.0	382.4	369.7	369.4	450.2	336.5	396.7	471.3	187.7
NP-M77	331.9	318.6	318.2	403.1	283.7	347.0	425.3	401.5	388.2	387.9	472.7	353.3	416.6	494.9	197.0
NM-M78	133.5	221.3	162.1	218.3	168.6	232.5	145.7	138.6	138.6	138.6	138.6	138.6	138.6	138.6	174.9
NP-M81	78.2	87.8	90.7	111.5	82.9	104.1	96.2	142.4	152.0	155.0	175.7	147.2	168.3	160.5	58.0
NP-M82	70.7	79.4	82.1	100.9	75.0	94.2	87.1	128.8	137.5	140.2	159.0	133.1	152.3	145.2	52.5
NP-M83	52.2	53.3	43.4	55.1	49.5	68.2	40.5	85.4	86.5	76.6	88.3	82.7	101.4	73.7	63.6
NP-M84	47.2	48.2	39.3	49.8	44.8	61.7	36.6	77.3	78.3	69.3	79.9	74.9	91.8	66.7	57.6
NP-M85	90.4	93.8	89.0	97.6	85.8	93.5	94.0	257.0	260.4	255.6	264.2	252.3	260.1	260.6	55.2
NP-M86	81.8	84.8	80.5	88.3	77.6	84.6	85.1	232.5	235.6	231.3	239.1	228.3	235.3	235.8	50.0
NP-M87	69.1	85.2	56.5	74.4	59.2	77.4	61.3	67.1	83.1	54.5	72.4	57.2	75.3	59.3	68.5
NP-M88	76.4	94.1	62.4	82.2	65.4	85.5	67.7	74.1	91.9	60.2	80.0	63.2	83.3	65.5	75.7
NP-M89	25.7	27.8	25.7	25.7	25.7	25.7	25.7	50.4	52.5	50.4	50.4	50.4	50.4	50.4	28.6
NP-M90	28.4	30.7	28.4	28.4	28.4	28.4	28.4	55.7	58.0	55.7	55.7	55.7	55.7	55.7	31.6
NP-M91	98.5	107.5	99.7	129.1	90.6	109.1	127.7	129.8	138.8	131.1	160.4	121.9	140.4	159.0	63.3
NP-M92	103.6	113.1	105.0	135.9	95.4	114.8	134.4	136.6	146.1	138.0	168.9	128.3	147.8	167.4	66.7
NP-M93	108.8	118.8	110.2	142.7	100.1	120.6	141.2	143.4	153.4	144.9	177.3	134.8	155.2	175.8	70.0
NP-M94	69.3	65.3	50.3	67.5	59.1	87.9	48.9	123.9	119.8	104.9	122.1	113.7	142.4	103.5	68.9
NP-M95	73.0	68.7	53.0	71.1	62.2	92.5	51.5	130.4	126.1	110.4	128.5	119.6	149.9	108.9	72.5
NP-M96	76.6	72.1	55.6	74.7	65.3	97.1	54.1	136.9	132.4	115.9	134.9	125.6	157.4	114.3	76.1
NP-M97	52.7	69.4	44.3	54.2	46.2	59.8	42.7	79.6	96.2	71.2	81.1	73.1	86.6	69.5	44.9
NP-M98	58.2	76.7	49.0	59.9	51.1	66.1	47.2	87.9	106.4	78.7	89.6	80.8	95.8	76.9	49.6
NP-M99	214.6	523.3	226.3	336.7	181.5	285.2	377.7	207.5	504.3	219.3	317.7	174.4	266.1	370.6	178.0
NP-M102	198.9	485.3	207.9	311.4	166.2	263.0	343.3	191.9	466.3	200.8	292.4	159.2	244.0	336.3	165.2
NP-M103	43.1	47.9	42.0	42.0	42.6	67.9	48.1	48.3	53.2	47.2	67.4	47.8	67.9	53.3	61.1
NP-M104	47.9	53.3	46.7	46.7	47.3	75.5	53.4	53.7	59.1	52.5	74.9	53.1	75.5	59.2	67.9
NP-M105	52.6	58.6	51.3	51.3	52.0	83.0	58.7	59.0	65.0	57.7	82.4	58.4	83.0	65.1	74.7
NP-M106	247.4	280.3	251.9	290.0	238.4	265.4	311.0	331.3	364.1	335.8	373.9	322.3	349.3	394.9	137.3
NP-M107	222.9	251.1	229.2	265.8	216.0	241.5	289.3	333.5	361.7	339.8	376.4	326.6	352.1	399.9	135.3

Table E-5 (cont.)

NP-M108	252.5	278.9	258.5	295.2	244.3	270.2	318.4	361.4	387.9	367.4	404.1	353.2	379.1	427.3	129.4
CP-M1	170.8	225.2	154.4	242.7	159.2	254.1	169.2	174.2	192.3	174.2	192.3	192.3	174.2	174.2	226.1
CP-M2	179.7	237.0	162.6	255.4	167.6	267.4	178.1	183.4	202.4	183.4	202.4	202.4	183.4	183.4	238.0
CP-M3	188.7	248.9	170.7	268.2	176.0	280.8	187.0	192.6	212.6	192.6	212.6	212.6	192.6	192.6	249.9
CP-M4	195.3	259.1	177.0	278.8	182.4	291.6	193.6	199.2	222.1	199.2	222.1	222.1	199.2	199.2	263.6
CP-M5	215.9	286.4	195.6	308.1	201.6	322.3	214.0	220.2	245.5	220.2	245.5	245.5	220.2	220.2	291.3
CP-M6	248.4	329.4	231.7	361.7	237.6	379.0	263.9	252.5	279.3	252.5	279.3	279.3	252.5	252.5	330.7
CP-M7	303.6	402.6	283.2	442.1	290.4	463.2	322.5	308.6	341.3	308.6	341.3	341.3	308.6	308.6	404.2
CP-M8	248.4	329.4	231.7	361.7	237.6	379.0	263.9	252.5	279.3	252.5	279.3	279.3	252.5	252.5	330.7
CP-M9	276.0	366.0	257.4	401.9	264.0	421.1	293.2	280.5	310.3	280.5	310.3	310.3	280.5	280.5	367.4
CP-M10	289.8	384.3	270.3	422.0	277.2	442.1	307.8	294.6	325.8	294.6	325.8	325.8	294.6	294.6	385.8
CP-M11	220.8	292.8	205.9	321.5	211.2	336.9	234.5	224.4	248.2	224.4	248.2	248.2	224.4	224.4	293.9
CP-M12	303.6	402.6	283.2	442.1	290.4	463.2	322.5	308.6	341.3	308.6	341.3	341.3	308.6	308.6	404.2
CP-M13	289.8	384.3	270.3	422.0	277.2	442.1	307.8	294.6	325.8	294.6	325.8	325.8	294.6	294.6	385.8
CP-M14	276.0	366.0	257.4	401.9	264.0	421.1	293.2	280.5	310.3	280.5	310.3	310.3	280.5	280.5	367.4
CP-M15	303.6	402.6	283.2	442.1	290.4	463.2	322.5	308.6	341.3	308.6	341.3	341.3	308.6	308.6	404.2
CP-M16	303.6	402.6	283.2	442.1	290.4	463.2	322.5	308.6	341.3	308.6	341.3	341.3	308.6	308.6	404.2
CP-M17	248.4	329.4	231.7	361.7	237.6	379.0	263.9	252.5	279.3	252.5	279.3	279.3	252.5	252.5	330.7
CP-M20	257.6	370.9	207.5	303.5	220.9	309.0	250.4	299.2	412.6	249.1	345.1	262.5	246.9	292.0	279.2
CP-M21	263.4	379.4	212.2	310.4	225.9	316.0	256.1	306.0	421.9	254.8	352.9	268.5	252.5	298.7	285.6
CP-M22	269.3	387.8	216.9	317.3	230.9	323.0	261.8	312.8	431.3	260.5	360.8	274.4	258.1	305.3	291.9
CP-M23	275.1	396.2	221.7	324.2	235.9	330.1	267.5	319.6	440.7	266.1	368.6	280.4	263.7	312.0	298.2
CP-M24	281.0	404.7	226.4	331.0	240.9	337.1	273.2	326.4	450.1	271.8	376.5	286.3	269.3	318.6	304.6
CP-M25	286.8	413.1	231.1	337.9	245.9	344.1	278.9	333.2	459.5	277.4	384.3	292.3	274.9	325.2	310.9
CP-M26	292.7	421.5	235.8	344.8	251.0	351.1	284.6	340.0	468.8	283.1	392.2	298.3	280.5	331.9	317.3
CP-M27	298.6	429.9	240.5	351.7	256.0	358.2	290.2	346.8	478.2	288.8	400.0	304.2	286.1	338.5	323.6
CP-M28	304.4	438.4	245.2	358.6	261.0	365.2	295.9	353.6	487.6	294.4	407.8	310.2	291.8	345.1	330.0
CP-M29	310.3	446.8	249.9	365.5	266.0	372.2	301.6	360.4	497.0	300.1	415.7	316.2	297.4	351.8	336.3
CP-M30	316.1	455.2	254.7	372.4	271.0	379.2	307.3	367.2	506.3	305.8	423.5	322.1	303.0	358.4	342.7
CP-M31	322.0	463.7	259.4	379.3	276.1	386.3	313.0	374.0	515.7	311.4	431.4	328.1	308.6	365.1	349.0
CP-M32	327.8	472.1	264.1	386.2	281.1	393.3	318.7	380.8	525.1	317.1	439.2	334.1	314.2	371.7	355.4
CP-M33	333.7	480.5	268.8	393.1	286.1	400.3	324.4	387.6	534.5	322.7	447.1	340.0	319.8	378.3	361.7
CP-M34	95.1	126.9	81.3	106.0	81.7	108.1	84.1	85.9	117.7	72.1	96.8	72.5	98.9	74.9	95.3
CP-M35	98.2	130.9	83.9	109.4	84.3	111.6	86.8	88.6	121.4	74.4	99.9	74.8	102.1	77.3	98.4
CP-M36	101.2	135.0	86.5	112.8	86.9	115.0	89.5	91.4	125.2	76.7	103.0	77.1	105.2	79.7	101.4
CP-M37	103.2	137.7	88.3	115.1	88.6	117.3	91.3	93.2	127.7	78.2	105.1	78.6	107.3	81.3	103.4

Table E-5 (cont.)

CP-M38	105.2	140.4	90.0	117.3	90.4	119.6	93.1	95.0	130.2	79.8	107.1	80.2	109.4	82.9	105.5
CP-M39	107.3	143.1	91.7	119.6	92.1	121.9	94.9	96.9	132.7	81.3	109.2	81.7	111.5	84.5	107.5
CP-M40	73.7	123.1	62.0	99.0	57.5	95.2	78.4	78.7	128.1	67.0	104.0	62.5	100.2	83.4	72.3
CP-M41	77.7	130.0	65.4	104.5	60.7	100.5	82.7	83.0	135.2	70.7	109.8	66.0	105.8	88.0	76.3
CP-M42	81.8	136.8	68.9	110.0	63.9	105.8	87.1	87.4	142.4	74.4	115.6	69.4	111.4	92.6	80.3
CP-M43	90.0	150.5	75.8	121.0	70.3	116.4	95.8	96.1	156.6	81.9	127.1	76.4	122.5	101.9	88.3
SP-M1	165.5	165.5	165.5	165.5	165.5	165.5	165.5	296.2	296.2	296.2	296.2	296.2	296.2	296.2	102.8
SP-M2	169.1	169.1	169.1	169.1	169.1	169.1	169.1	302.7	302.7	302.7	302.7	302.7	302.7	302.7	105.0
SP-M3	172.7	172.7	172.7	172.7	172.7	172.7	172.7	309.1	309.1	309.1	309.1	309.1	309.1	309.1	107.2
SP-M4	176.3	176.3	176.3	176.3	176.3	176.3	176.3	315.5	315.5	315.5	315.5	315.5	315.5	315.5	109.5
SP-M5	179.9	179.9	179.9	179.9	179.9	179.9	179.9	322.0	322.0	322.0	322.0	322.0	322.0	322.0	111.7
SP-M6	183.5	183.5	183.5	183.5	183.5	183.5	183.5	328.4	328.4	328.4	328.4	328.4	328.4	328.4	113.9
SP-M7	187.1	187.1	187.1	187.1	187.1	187.1	187.1	334.9	334.9	334.9	334.9	334.9	334.9	334.9	116.2
SP-M8	190.7	190.7	190.7	190.7	190.7	190.7	190.7	341.3	341.3	341.3	341.3	341.3	341.3	341.3	118.4
SP-M9	194.3	194.3	194.3	194.3	194.3	194.3	194.3	347.7	347.7	347.7	347.7	347.7	347.7	347.7	120.7
SP-M10	62.1	71.4	57.3	80.0	61.9	92.6	54.1	66.9	76.2	62.0	84.8	66.6	97.3	58.9	75.4
SP-M11	63.4	72.9	58.5	81.7	63.2	94.5	55.3	68.3	77.8	63.4	86.6	68.0	99.4	60.1	77.0
SP-M12	64.8	74.4	59.7	83.4	64.5	96.5	56.4	69.7	79.4	64.7	88.4	69.5	101.5	61.4	78.6
SP-M14	67.4	77.5	62.2	86.8	67.1	100.4	58.7	72.6	82.6	67.3	92.0	72.3	105.6	63.9	81.8
SP-M16	70.1	80.5	64.6	90.2	69.8	104.4	61.0	75.4	85.9	70.0	95.6	75.1	109.7	66.4	85.0
SP-M17	570.2	568.9	648.7	757.4	587.6	674.4	788.2	653.9	652.6	732.4	841.1	671.3	758.1	871.9	348.3
SP-M18	630.3	628.7	717.0	837.2	649.4	745.3	871.2	722.8	721.2	809.5	929.7	741.9	837.9	963.7	385.0
SP-M19	78.3	111.2	63.5	78.4	68.5	90.7	61.6	104.0	136.9	89.2	104.1	94.2	116.4	87.3	73.8
SP-M20	82.6	117.4	67.1	82.7	72.3	95.7	65.0	109.8	144.6	94.2	109.9	99.4	122.8	92.2	77.9
SP-M21	87.0	123.6	70.6	87.1	76.1	100.7	68.5	115.5	152.2	99.2	115.6	104.7	129.3	97.0	82.0
SP-M22	95.7	136.0	77.7	95.8	83.7	110.8	75.3	127.1	167.4	109.1	127.2	115.1	142.2	106.7	90.2
SP-M23	232.5	266.0	243.9	275.4	230.3	254.2	266.6	343.0	376.4	354.3	385.8	340.7	364.6	377.0	165.0
SP-M24	271.3	273.0	274.5	296.3	265.2	281.7	295.2	368.5	370.2	371.7	393.5	362.4	378.9	392.4	141.8
SP-M25	134.4	177.1	166.9	249.1	163.4	219.4	189.5	166.1	189.1	178.9	261.2	175.5	231.5	201.5	189.5
SP-M26	293.1	303.1	291.4	296.1	289.6	294.0	291.8	454.9	465.0	453.2	457.9	451.5	455.9	453.7	181.8
SP-M27	262.7	263.1	265.5	279.5	258.9	270.6	272.5	369.0	369.4	371.8	385.8	365.2	376.8	378.8	89.0
SP-M28	349.4	364.2	349.4	370.1	333.2	353.5	369.0	482.1	497.0	482.1	502.9	465.9	486.3	501.8	173.2

APPENDIX F
Histogram and Frequency Distribution of Bias Factor for Driven Piles from Vietnam

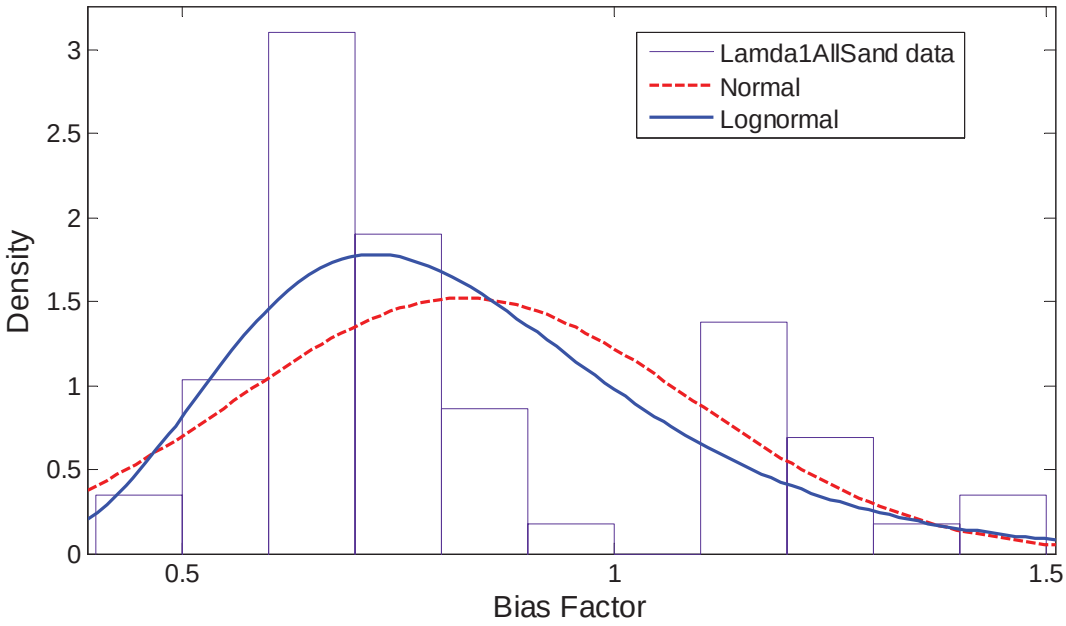


Figure F-S1-a Histogram and frequency distribution of bias factorλ1 for 58 cases of concrete piles in Sand using the Nordlund method (ϕ: Peck, Hanson and Thornbum) in Vietnam

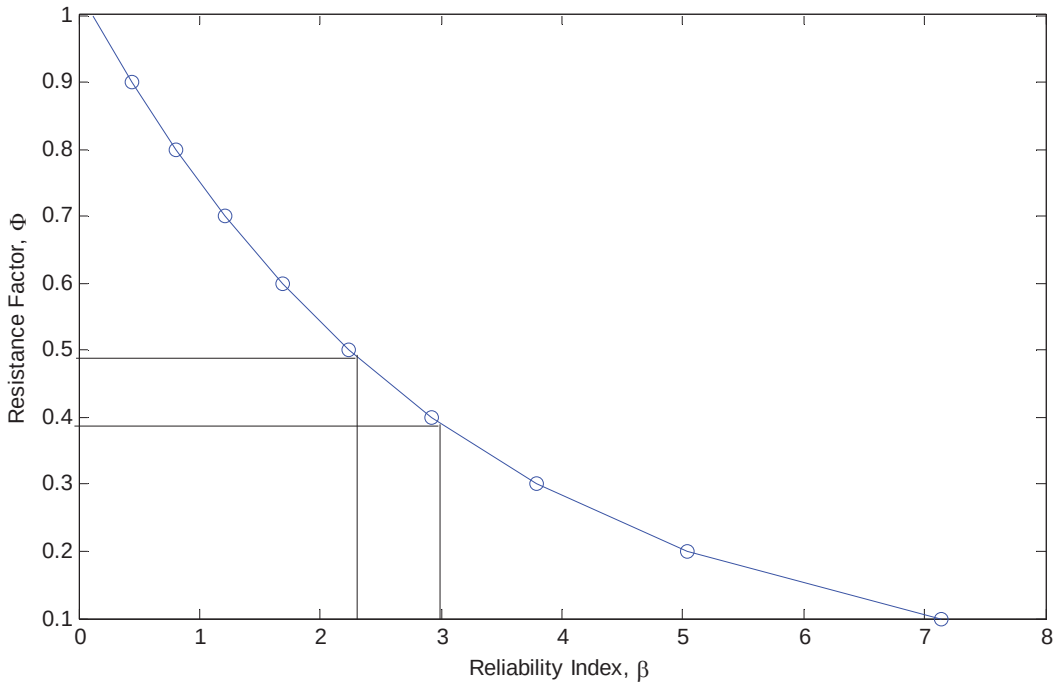


Figure F-S1-b Resistant factor calibration for 58 cases of concrete piles in Sand using the Nordlund method (ϕ: Peck, Hanson and Thornbum) in Vietnam

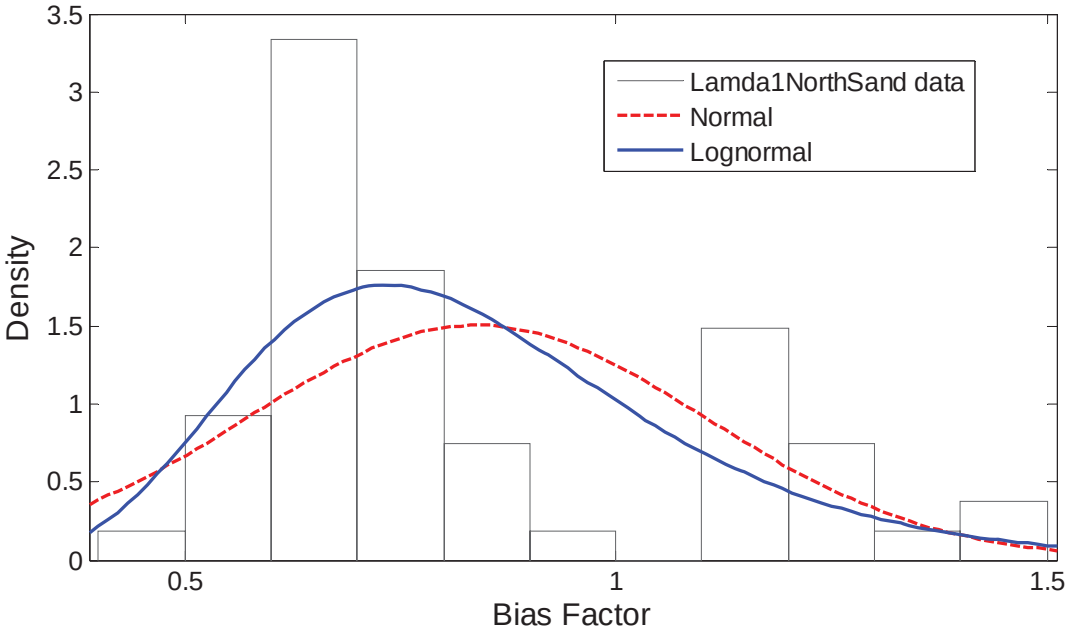


Figure F-S1-c Histogram and frequency distribution of bias factor for λ1 54cases of concrete piles in Sand using the Nordlundmethod (ϕ: Peck, Hanson and Thornbum)in North of Vietnam

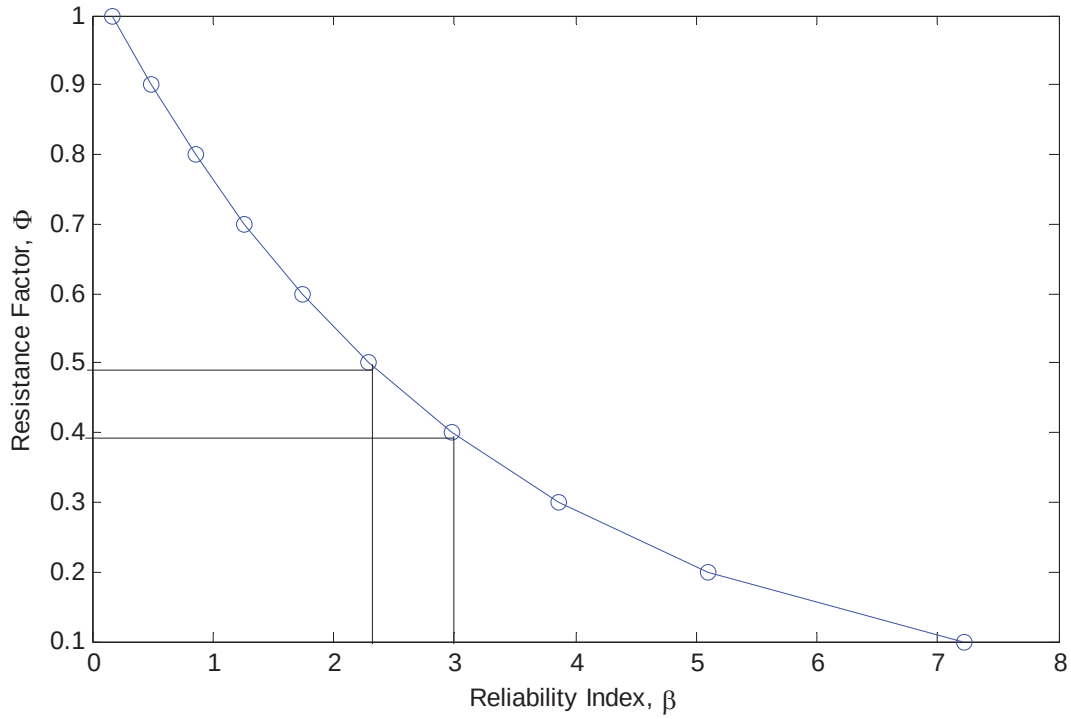


Figure F-S1-d Resistant factor calibration for54 cases of concrete piles in Sand using theNordlundmethod (ϕ: Peck, Hanson and Thornbum)in North of Vietnam

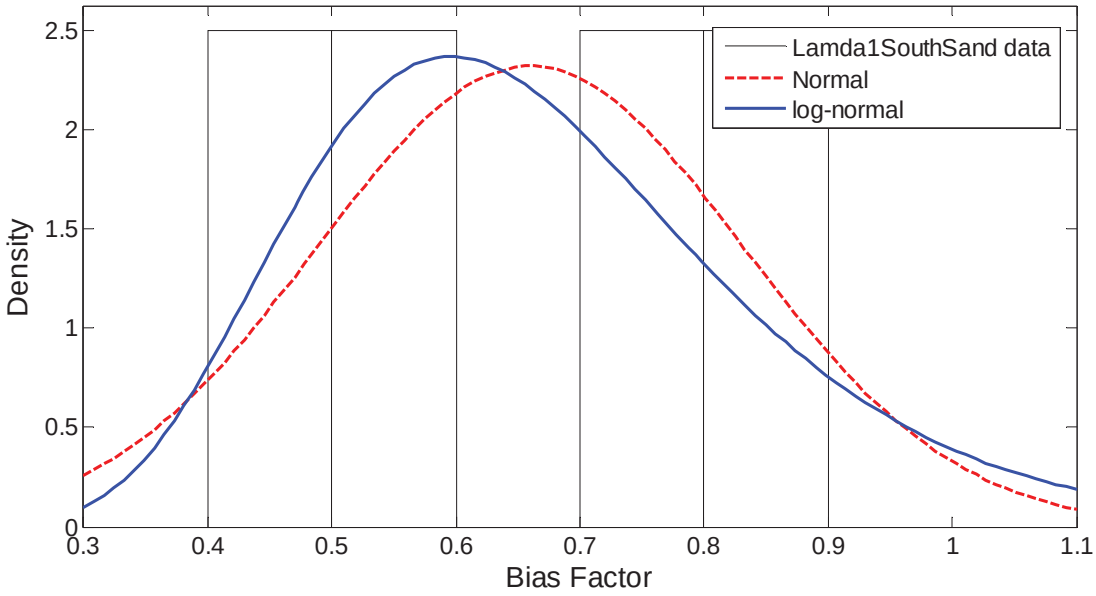


Figure F-S1-e Histogram and frequency distribution of bias factor λ1 for 4 cases of concrete piles in Sand using the Nordlundmethod (ϕ: Peck, Hanson and Thornbum)in South of Vietnam

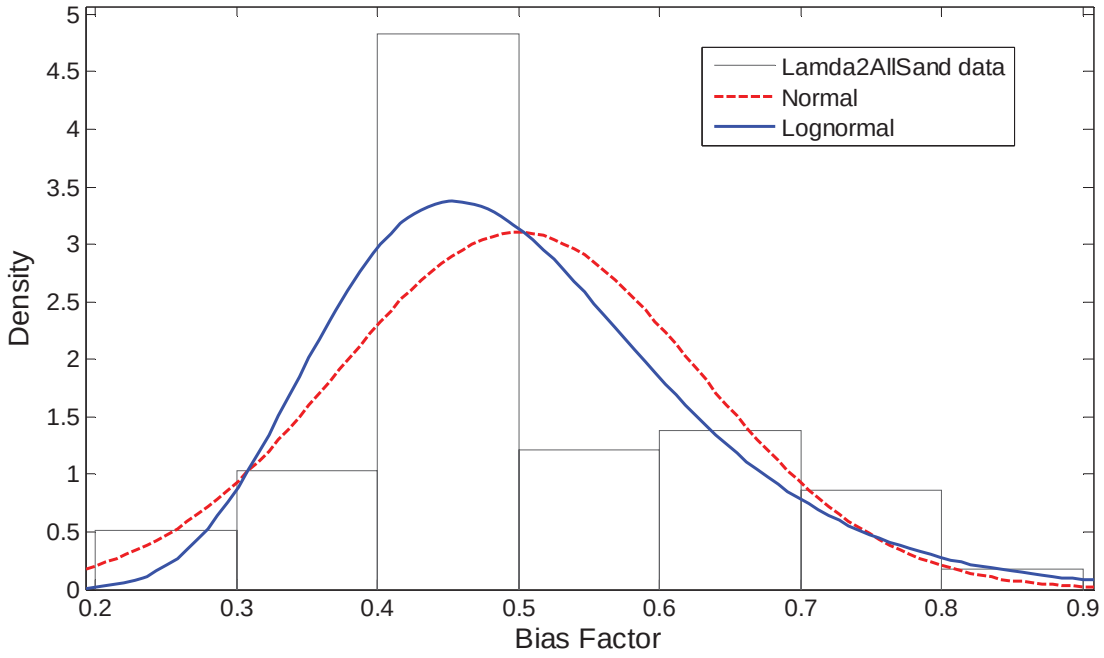


Figure F-S2-a: Histogram and frequency distribution of bias factor λ2 for 58 cases of concrete piles in Sand using the Nordlund method (ϕ: Schmertmann) in Vietnam

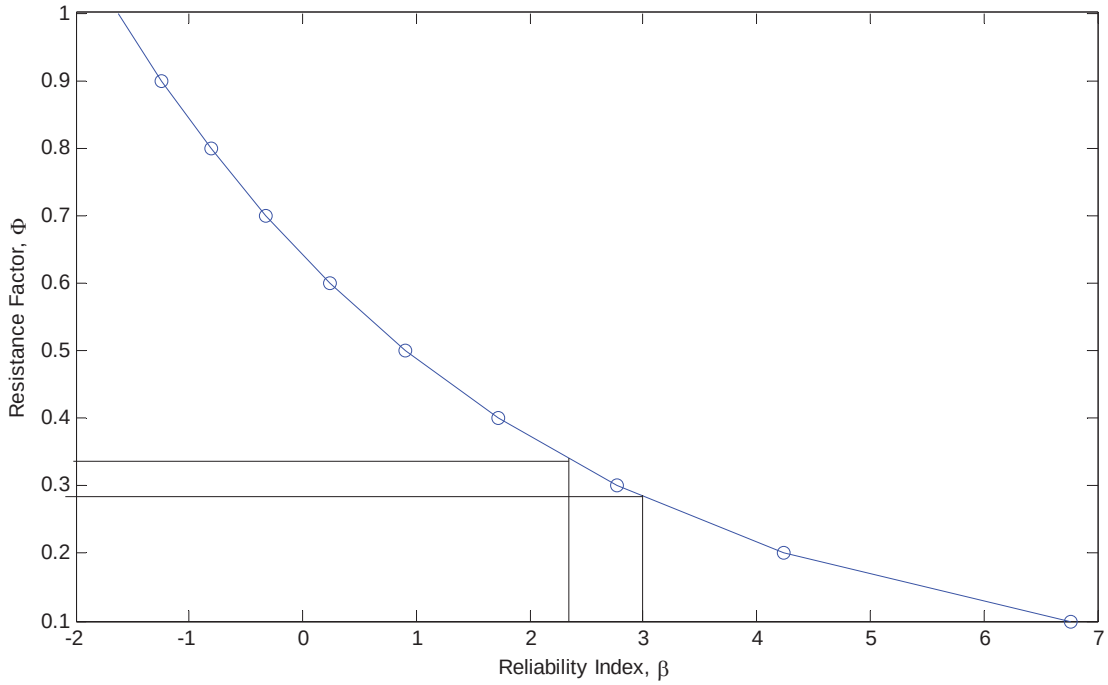


Figure F-S2-b Resistant factor calibration for 58 cases of concrete piles in Sand using the Nordlund method (ϕ: Schmertmann) in Vietnam

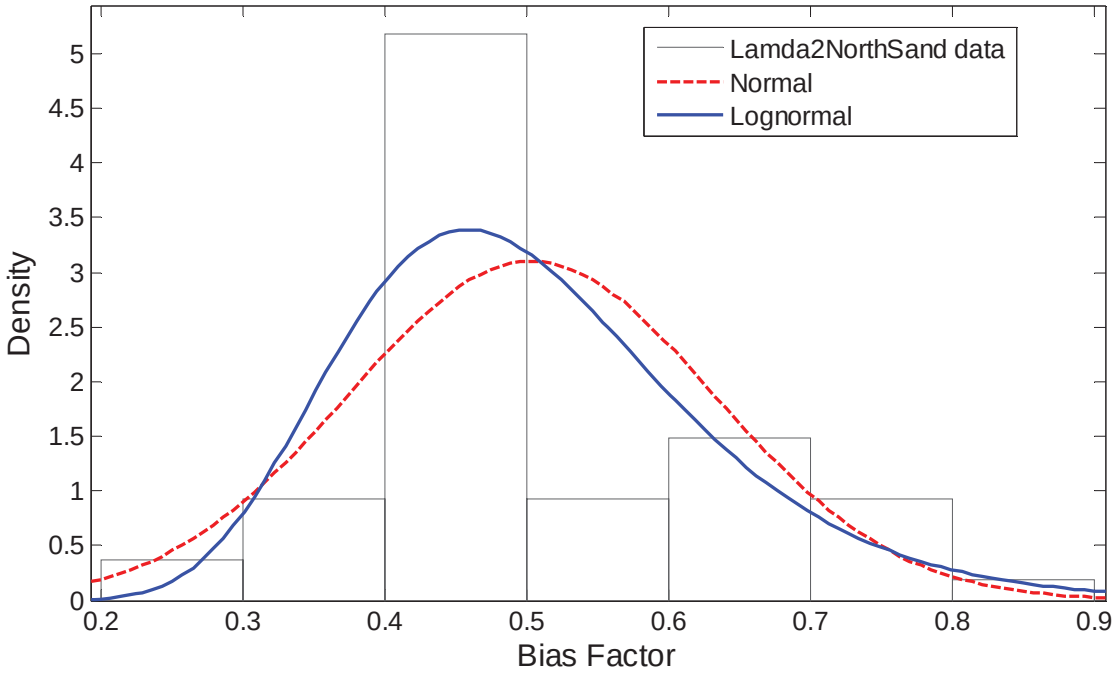


Figure F-S2-c Histogram and frequency distribution of bias factor λ2 for 54 cases of concrete piles in Sand using the Nordlundmethod (ϕ: Schmertmann)in North of Vietnam

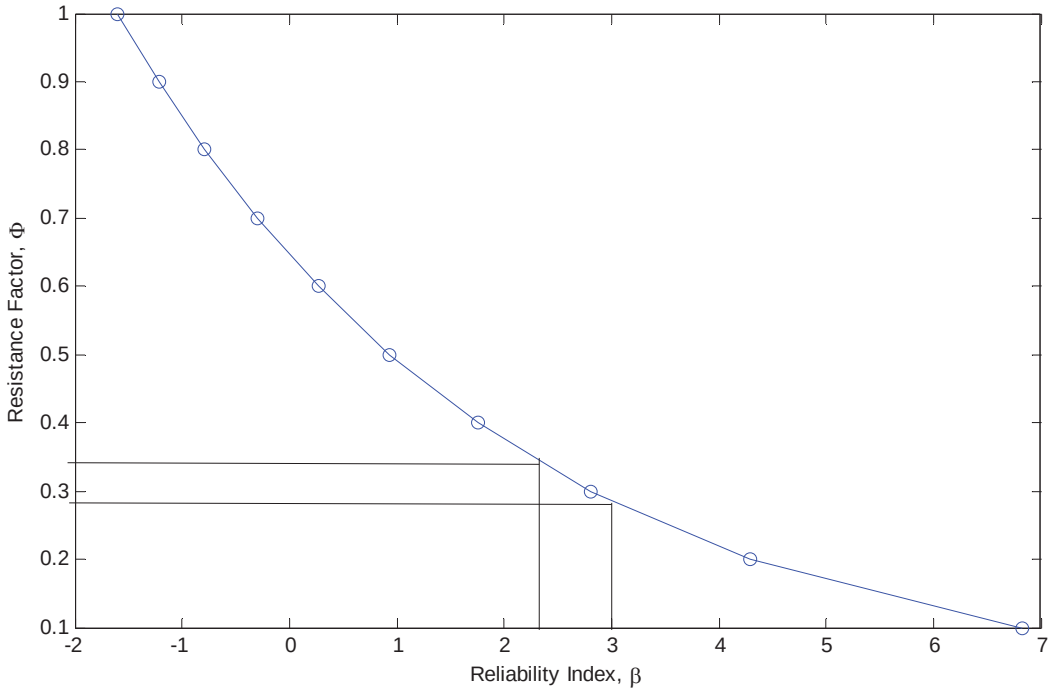


Figure F-S2-d Resistant factor calibration for 54 cases of concrete piles in Sand using the Nordlundmethod (ϕ: Schmertmann)in North of Vietnam

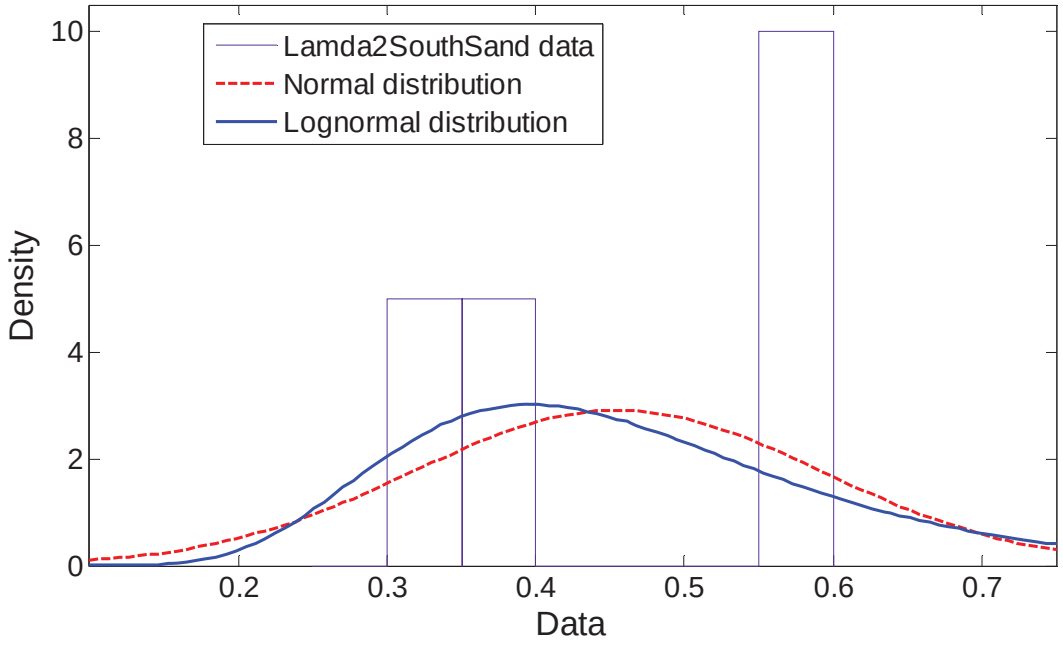


Figure F-S2-e Histogram and frequency distribution of bias factor λ2 for 4 cases of concrete piles in Sand using the Nordlundmethod (ϕ: Schmertmann)in South of Vietnam

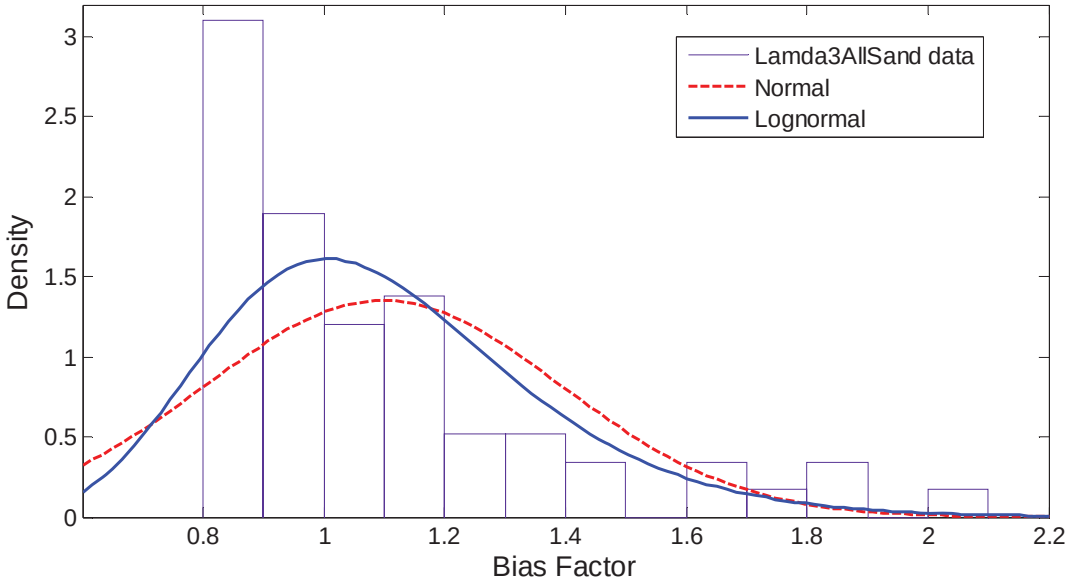


Figure F-S3-a: Histogram and frequency distribution of bias factor λ3 for 58 cases of concrete piles in Sand using the Meyerhof SPT methodin Vietnam

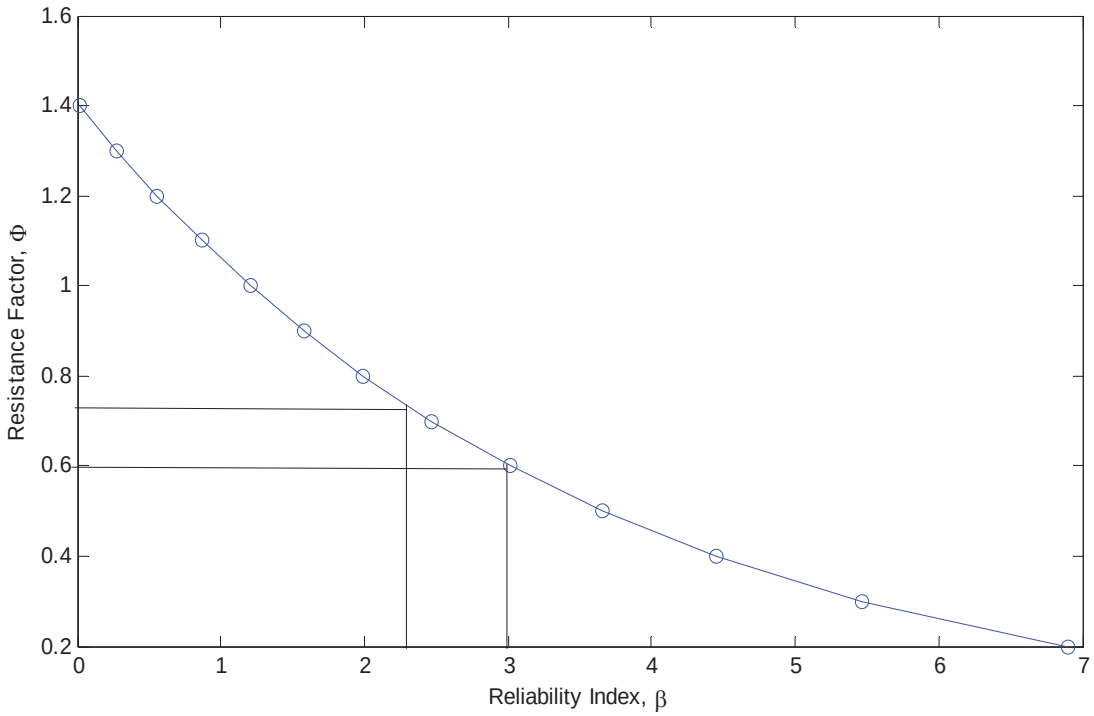


Figure F-S3-b: Resistant factor calibration for 58 cases of concrete piles in Sand using the Meyerhof SPT methodin Vietnam

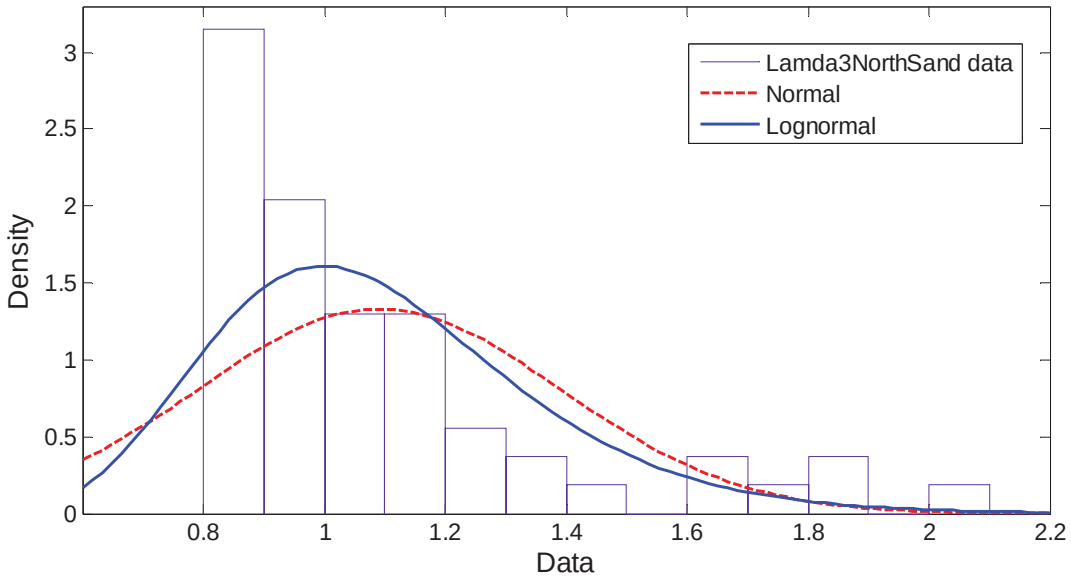


Figure F-S3-c: Histogram and frequency distribution of bias factor λ3 for 54 cases of concrete piles in Sand using the Meyerhof SPT methodin North of Vietnam

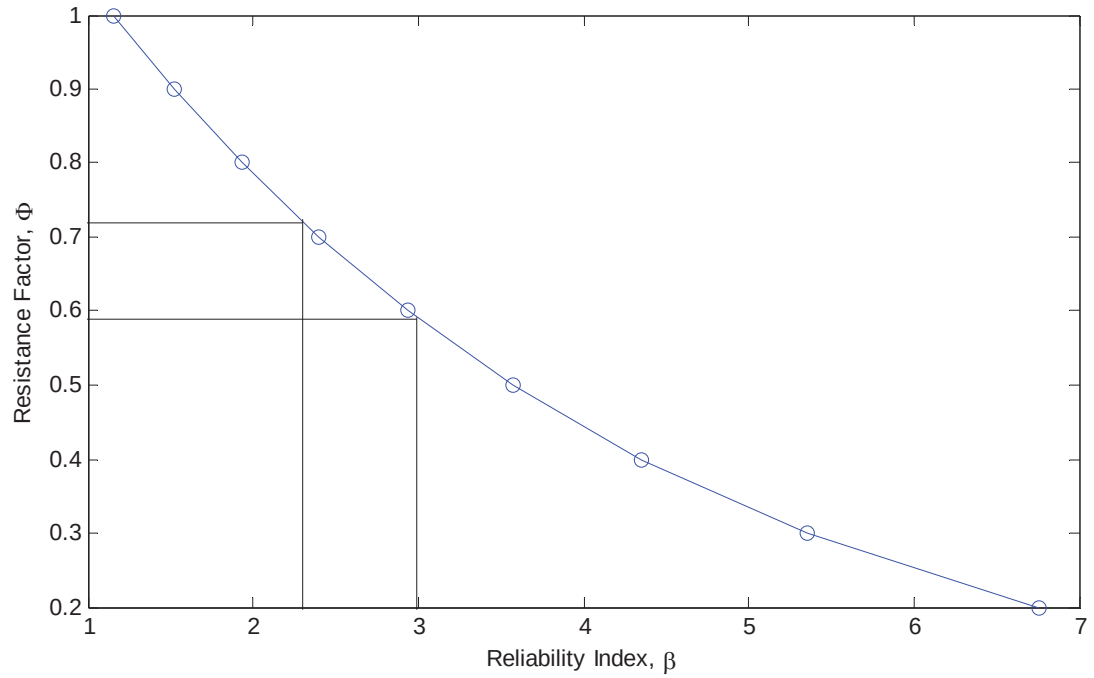


Figure F-S3-d Resistant factor calibration for 54 cases of concrete piles in Sand using the Meyerhof SPT methodin North of Vietnam

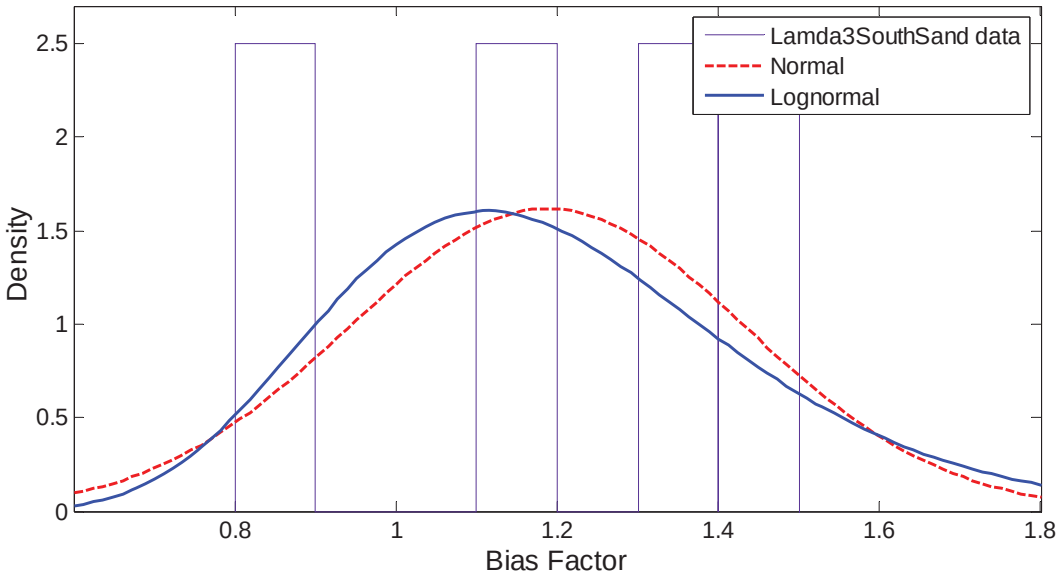


Figure F-S3-e Histogram and frequency distribution of bias factor λ3 for 4 cases of concrete piles in Sand using the Meyerhof SPT methodin South of Vietnam

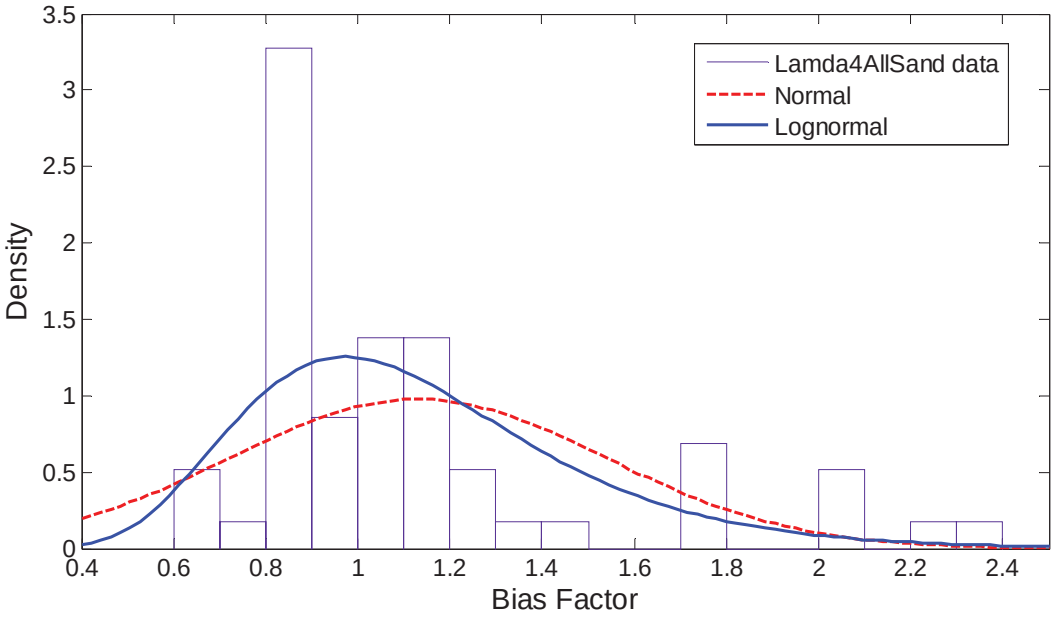


Figure F-S4-a: Histogram and frequency distribution of bias factor λ4 for 58 cases of concrete piles in Sand using the Schmertmann SPT methodin Vietnam

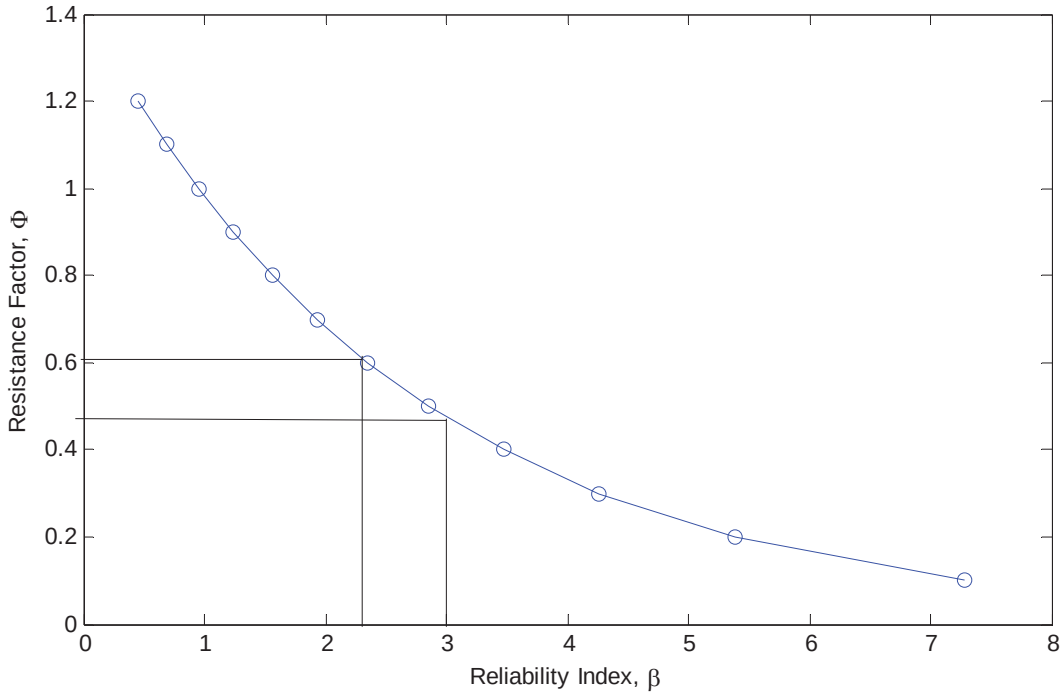


Figure F-S4-b: Resistant factor calibration for 58 cases of concrete piles in Sand using the Schmertmann SPT methodin Vietnam

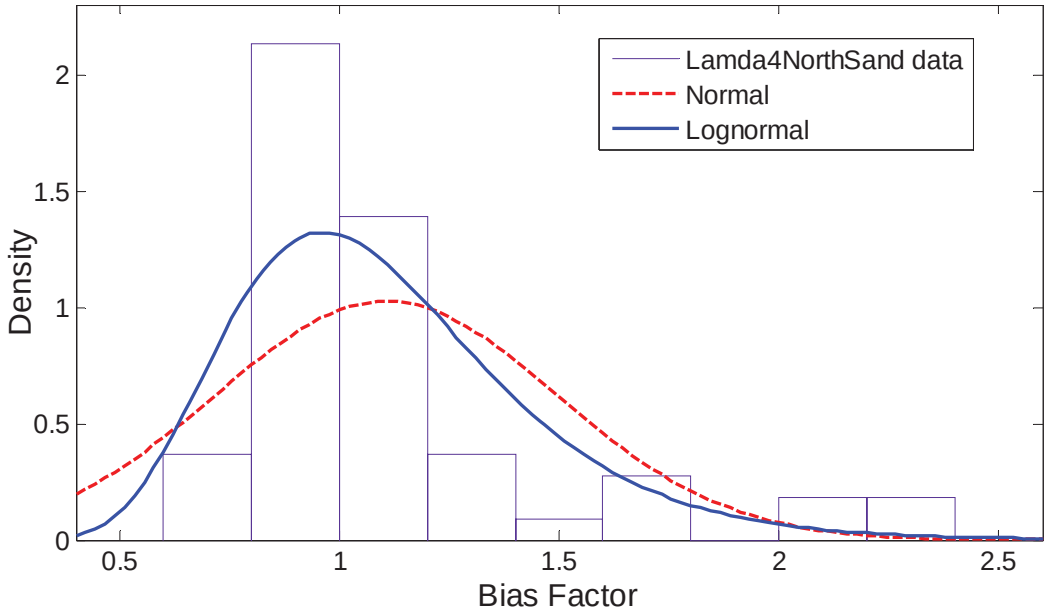


Figure F-S4-c: Histogram and frequency distribution of bias factor λ4 for 54 cases of concrete piles in Sand using the Schmertmann SPT methodin North of Vietnam

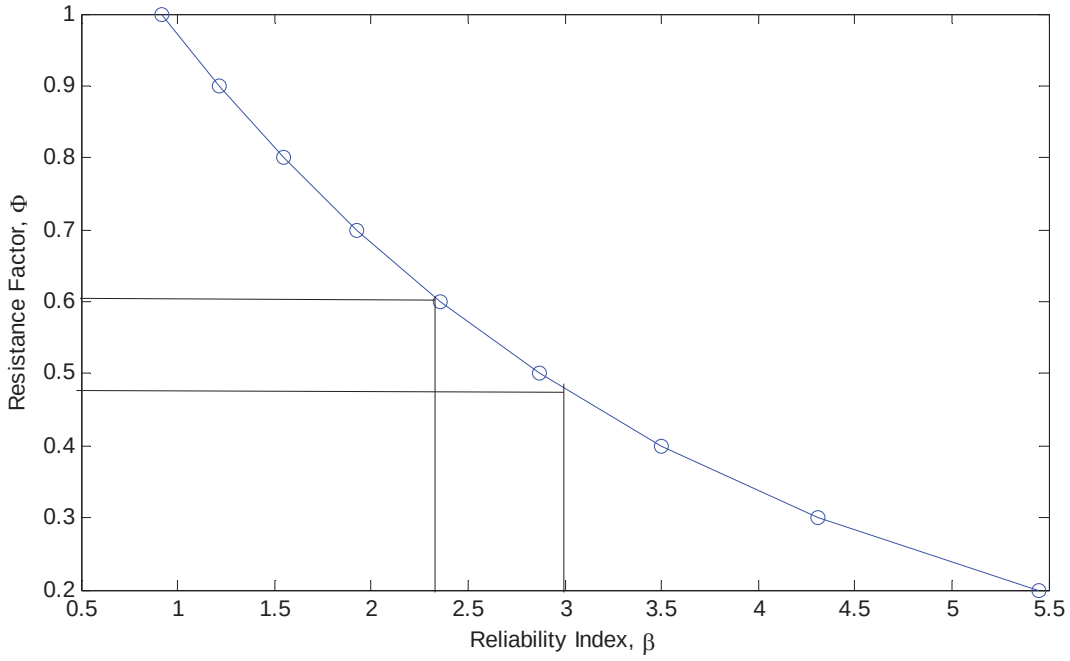


Figure F-S4-d: Resistant factor calibration for 54 cases of concrete piles in Sand using the Schmertmann SPT methodin North of Vietnam

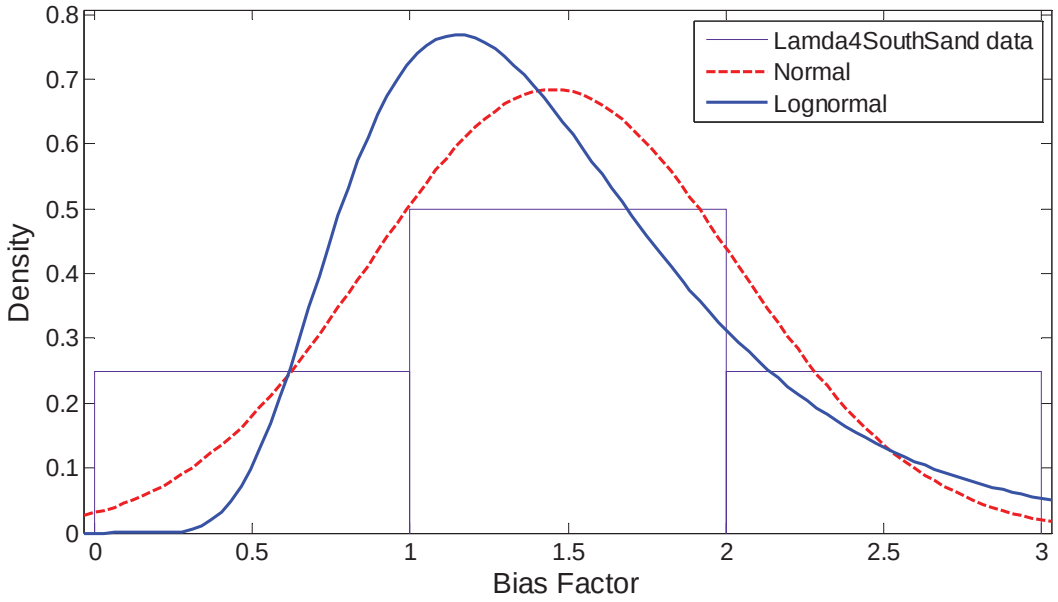


Figure F-S4-e: Histogram and frequency distribution of bias factor λ4 for 4 cases of concrete piles in Sand using the Schmertmann SPT methodin North of Vietnam

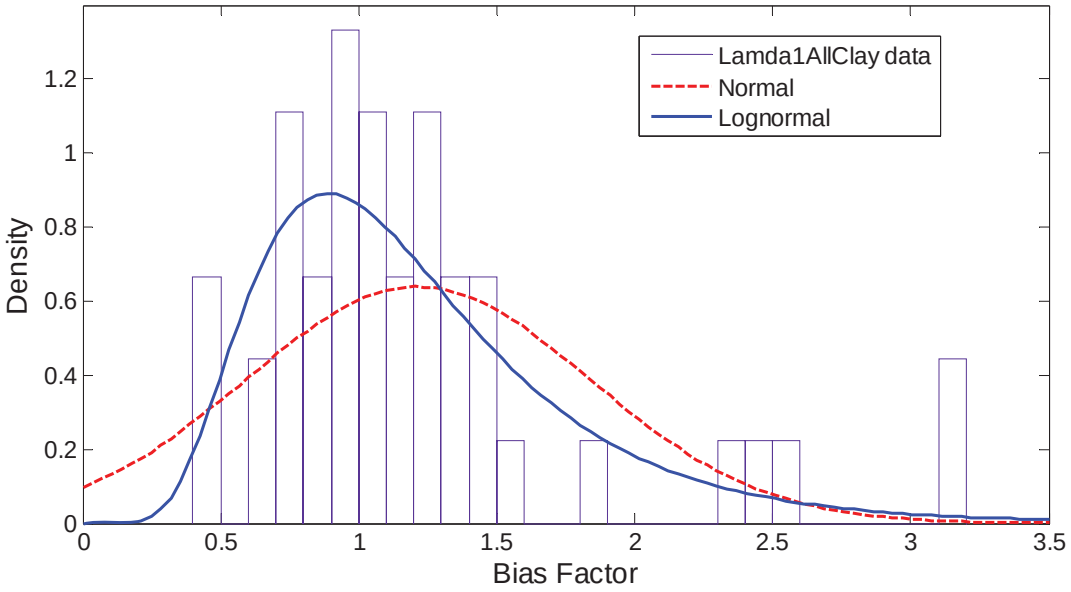


Figure F-C1-a: Histogram and frequency distribution of bias factor λ1 for 50cases of concrete piles in Clay using the α-Tomlinson method (Su: Peck) in Vietnam

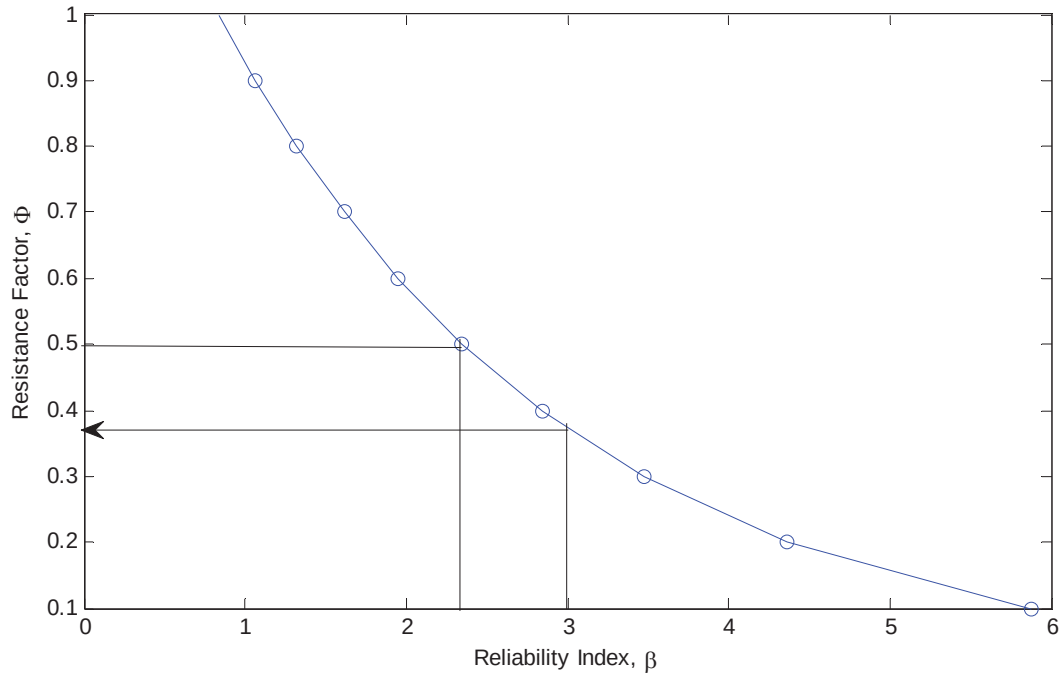


Figure F-C1-b: Resistant factor calibration for 50cases of concrete piles in Clay using the α-Tomlinson method (Su: Peck) in Vietnam

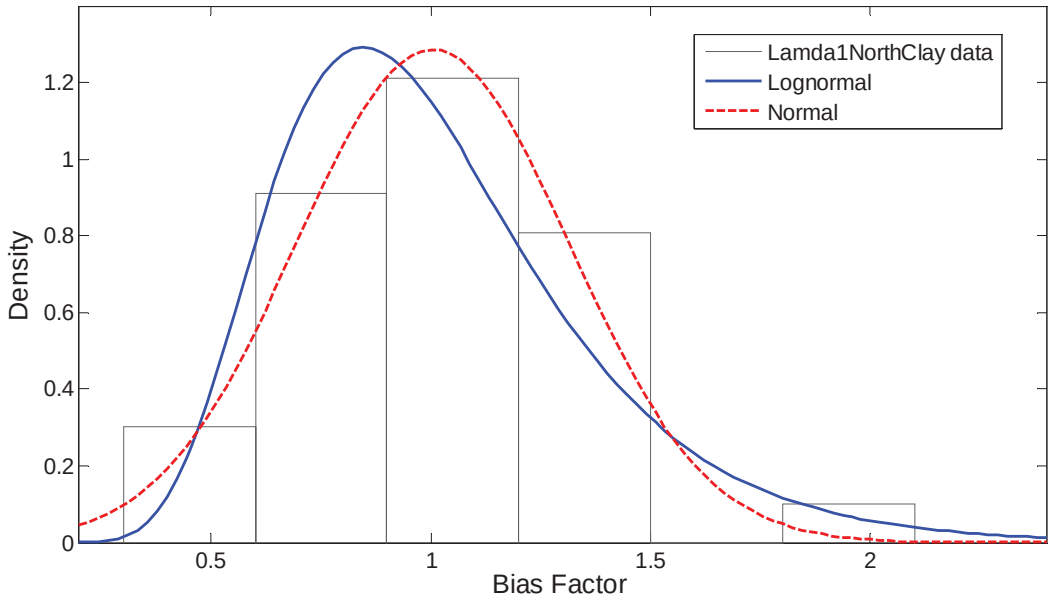


Figure F-C1-c Histogram and frequency distribution of λ1 for 38 cases of concrete piles in Clay using the α-Tomlinson method (Su: Peck) in Northof Vietnam

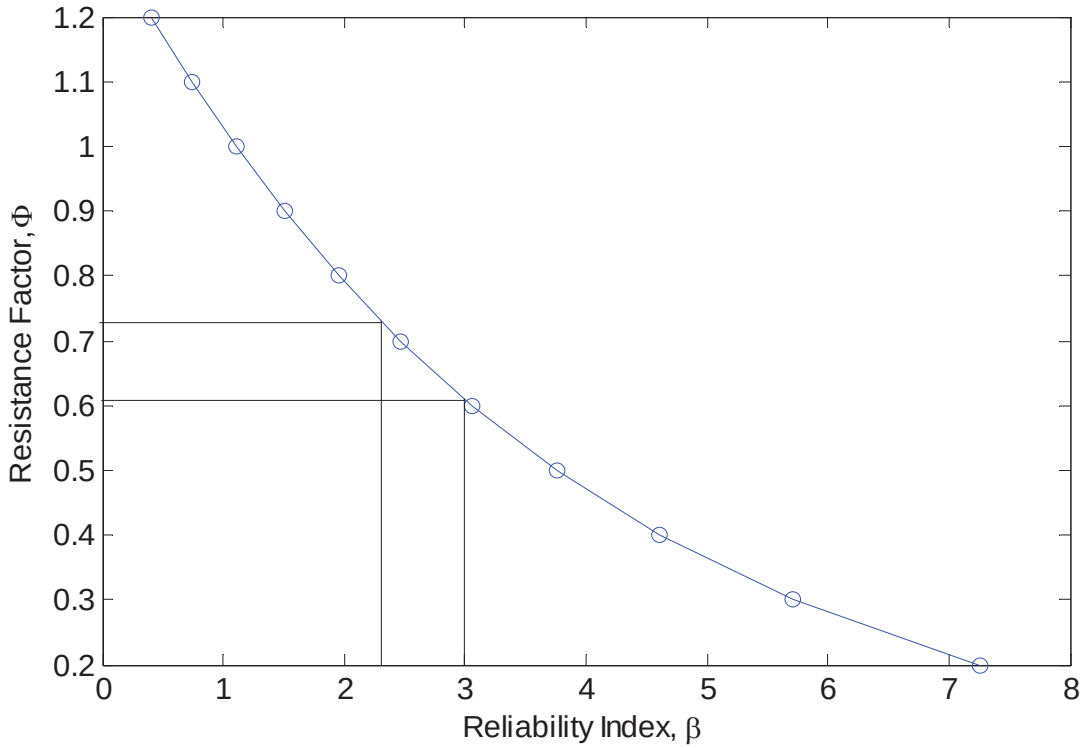


Figure F-C1-d Resistance factor calibration for 38 cases of concrete piles in Clay using the α-Tomlinson method (Su: Peck) in Northof Vietnam

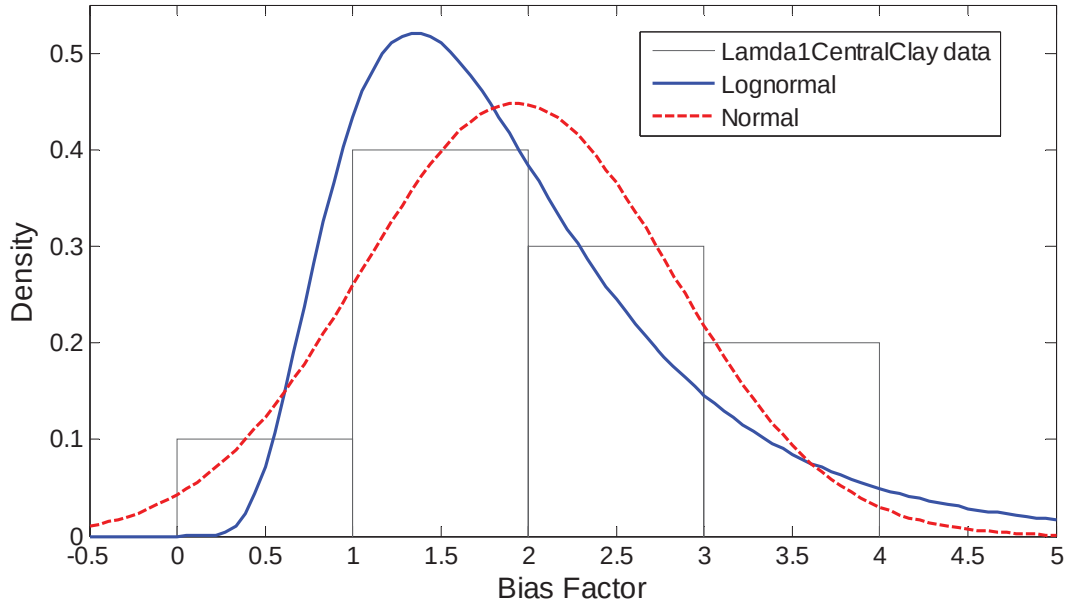


Figure F-C1-e Histogram and frequency distribution of λ1 for 10 cases of concrete piles in Clay using the α-Tomlinson method (Su: Peck) in Central of Vietnam

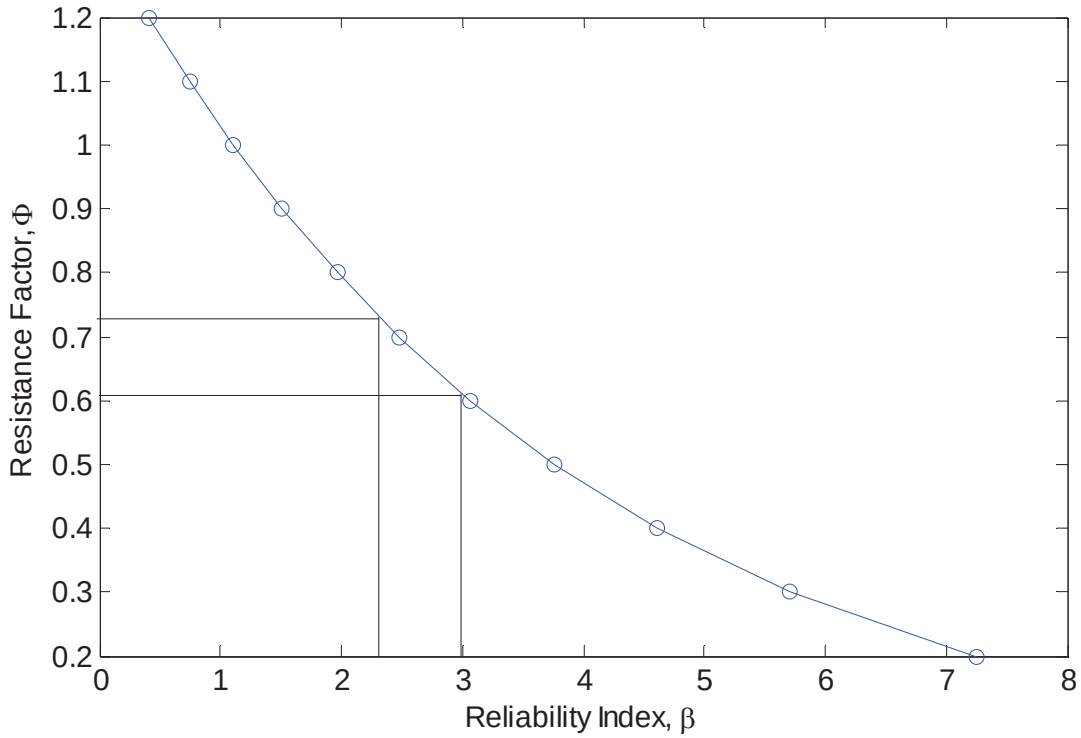


Figure F-C1-f Resistance factor calibration for 10 cases of concrete piles in Clay using the α-Tomlinson method (Su: Peck) in Central of Vietnam

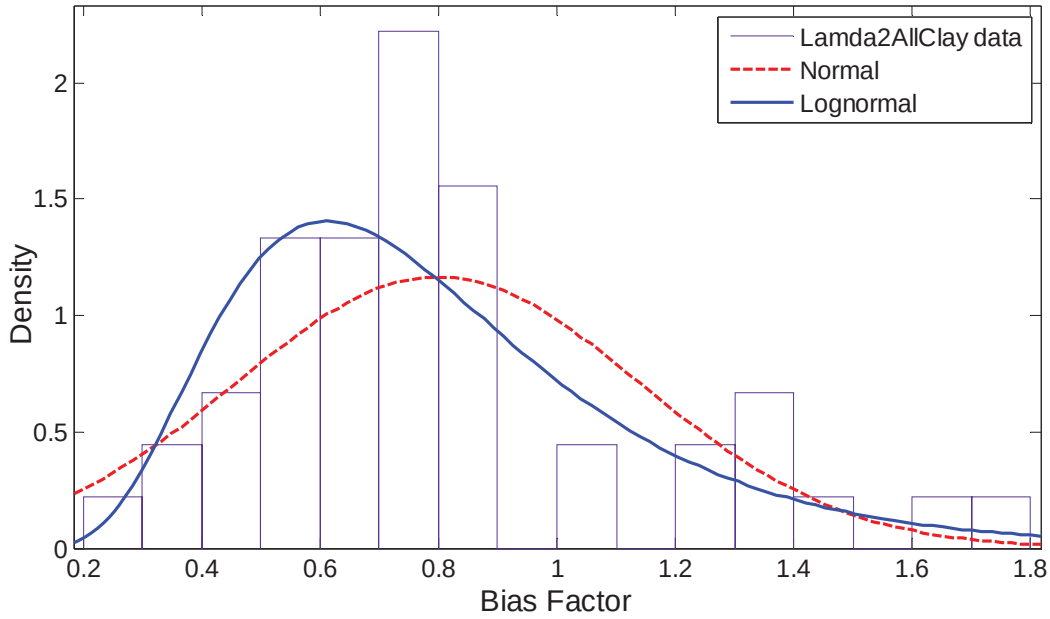


Figure F-C2-a Histogram and frequency distribution of bias factor λ2 for 50cases of concrete piles in Clay using the α-Tomlinson method (Su: Hara) in Vietnam

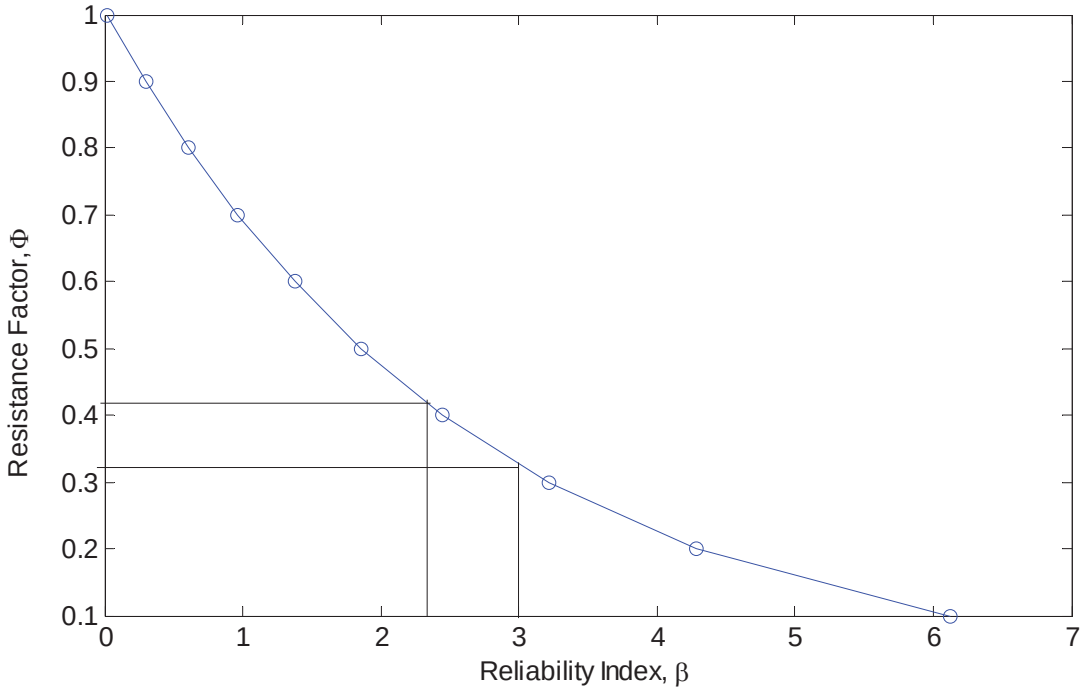


Figure F-C2-b Resistance factor calibration for 50cases of concrete piles in Clay using the α-Tomlinson method (Su: Hara) in Vietnam

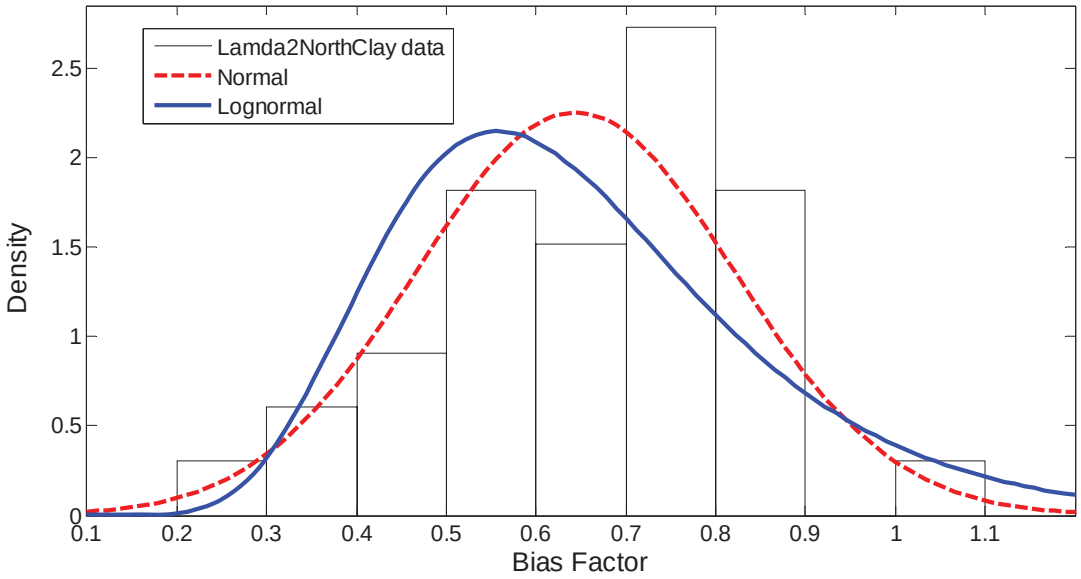


Figure F-C2-c Histogram and frequency distribution of bias factor λ2 for 38cases of concrete piles in Clay using the α-Tomlinson method (Su: Hara) in North of Vietnam

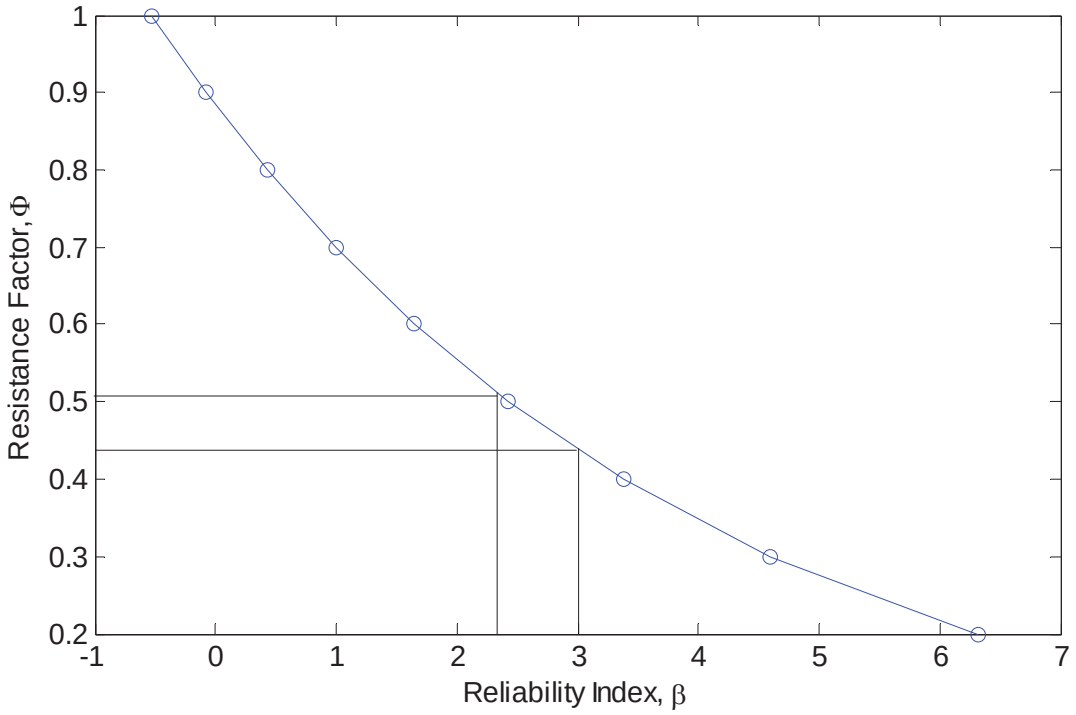


Figure F-C2-d Resistance factor calibration for 38cases of concrete piles in Clay using the α-Tomlinson method (Su: Hara) in North of Vietnam

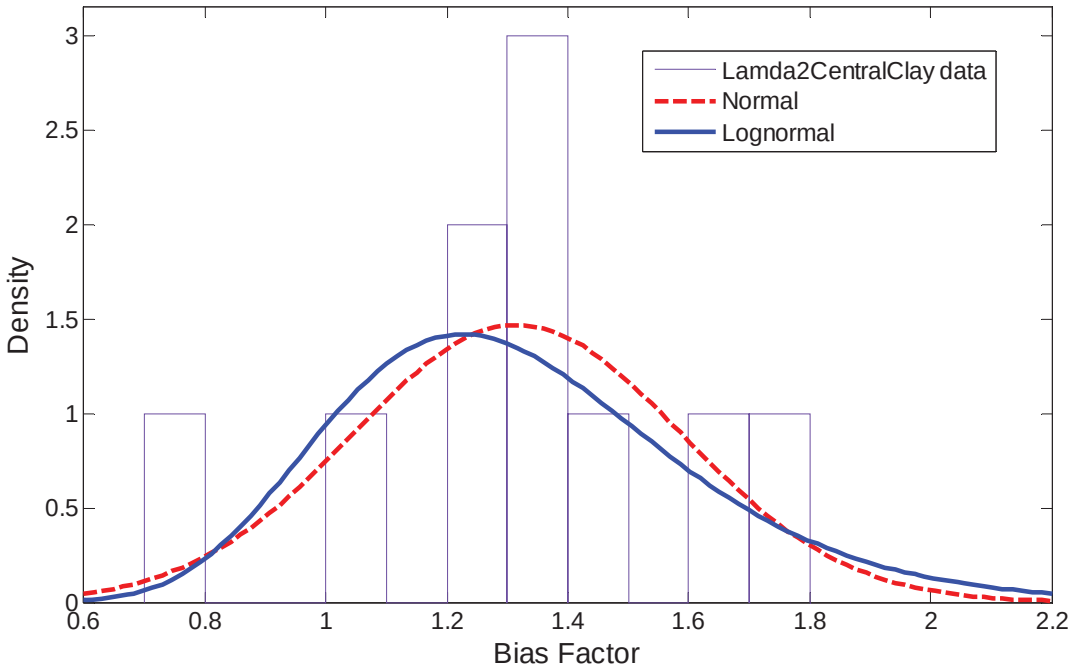


Figure F-C2-e Histogram and frequency distribution of bias factor λ2 for 10cases of concrete piles in Clay using the α-Tomlinson method (Su: Hara) in South of Vietnam

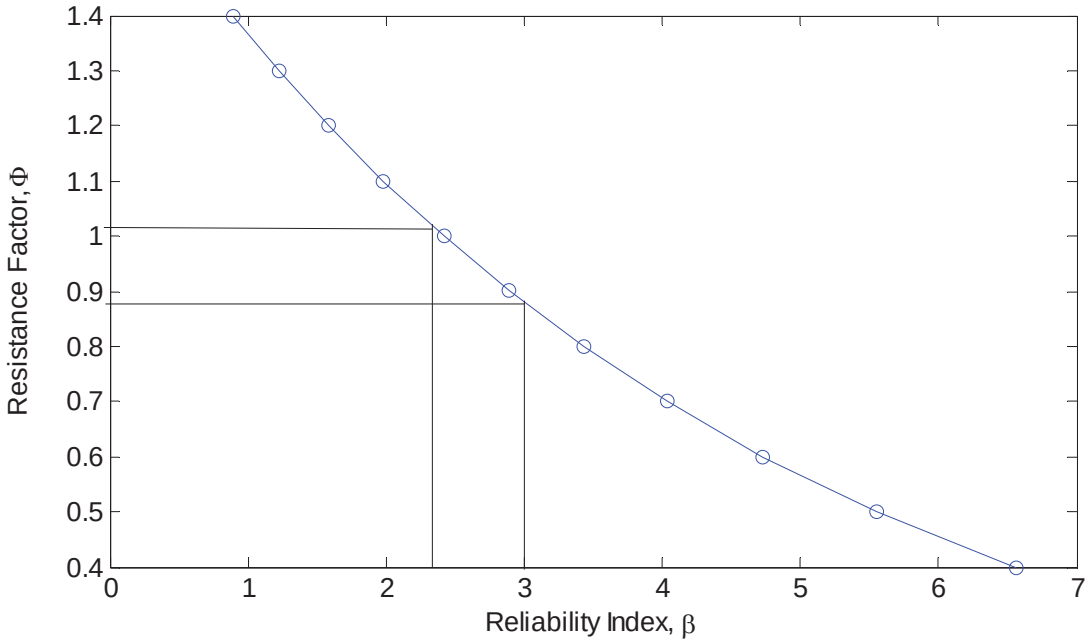


Figure FigureF-C2-f Resistance factor calibration for 10cases of concrete piles in Clay using the α-Tomlinson method (Su: Hara) in South of Vietnam

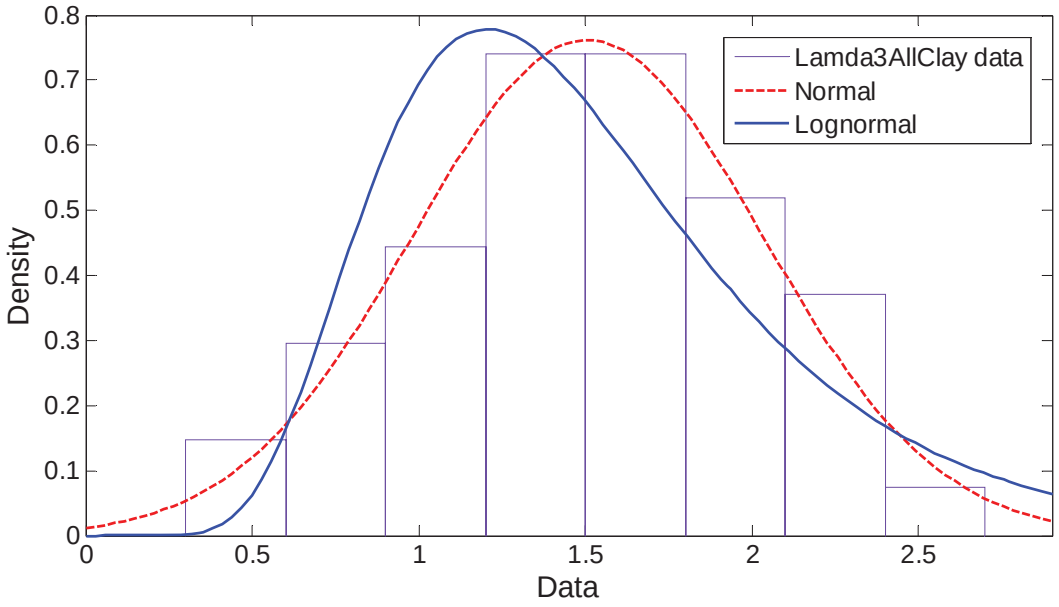


Figure Figure F-C3-a Histogram and frequency distribution of bias factor λ3 for 50cases of concrete piles in Clay using the α-API method (Su: Peck) in Vietnam

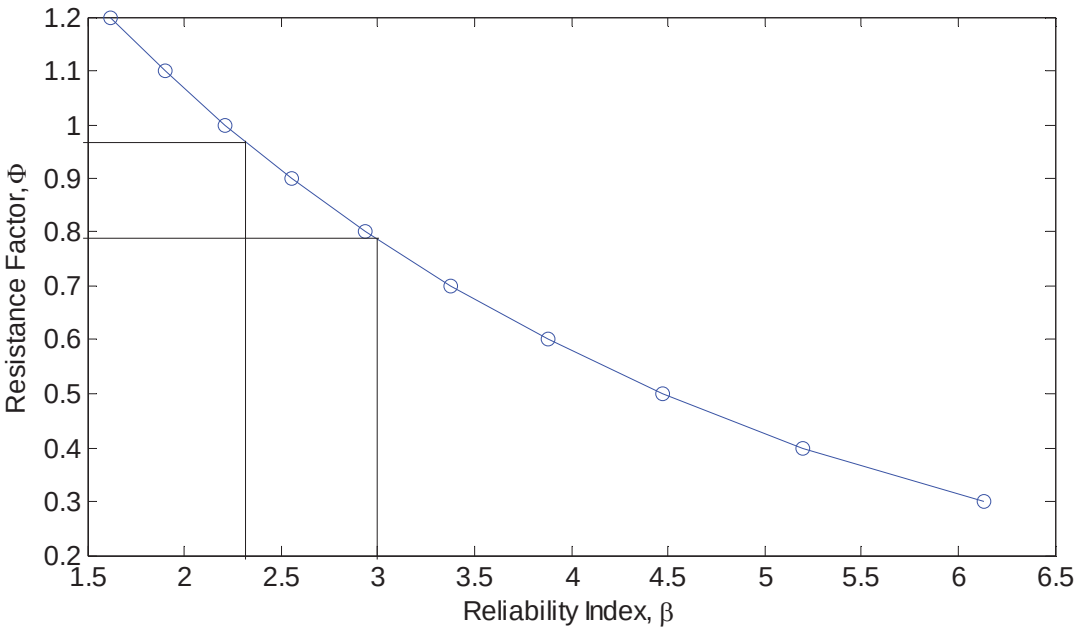


Figure Figure F-C3-b: Resistance factor calibration for 50cases of concrete piles in Clay using the α-API method (Su: Peck) in Vietnam

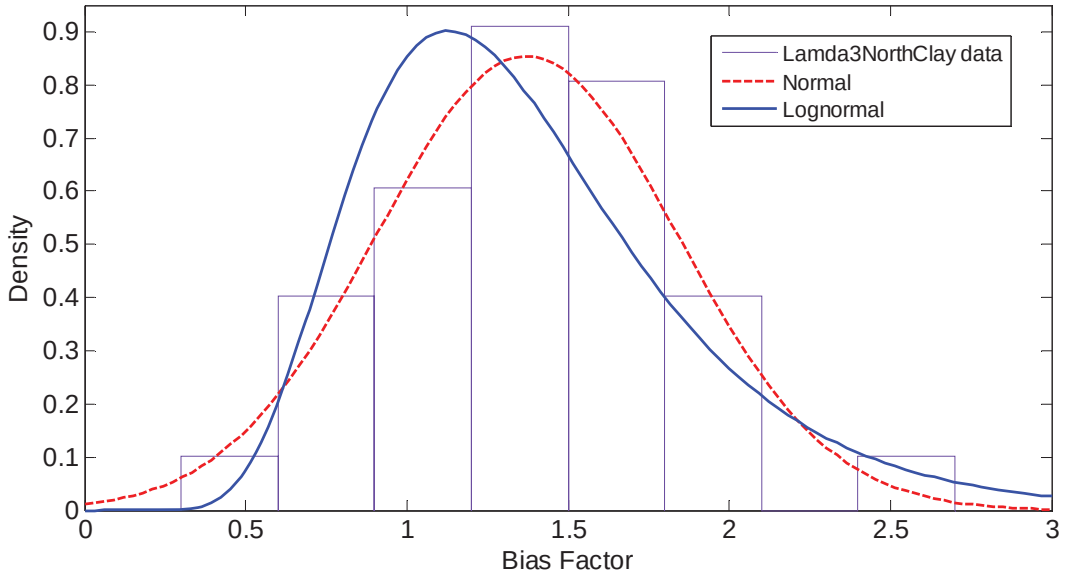


Figure F-C3-a Histogram and frequency distribution of bias factor λ3 for 38cases of concrete piles in Clay using the α-API method (Su: Peck) in North of Vietnam

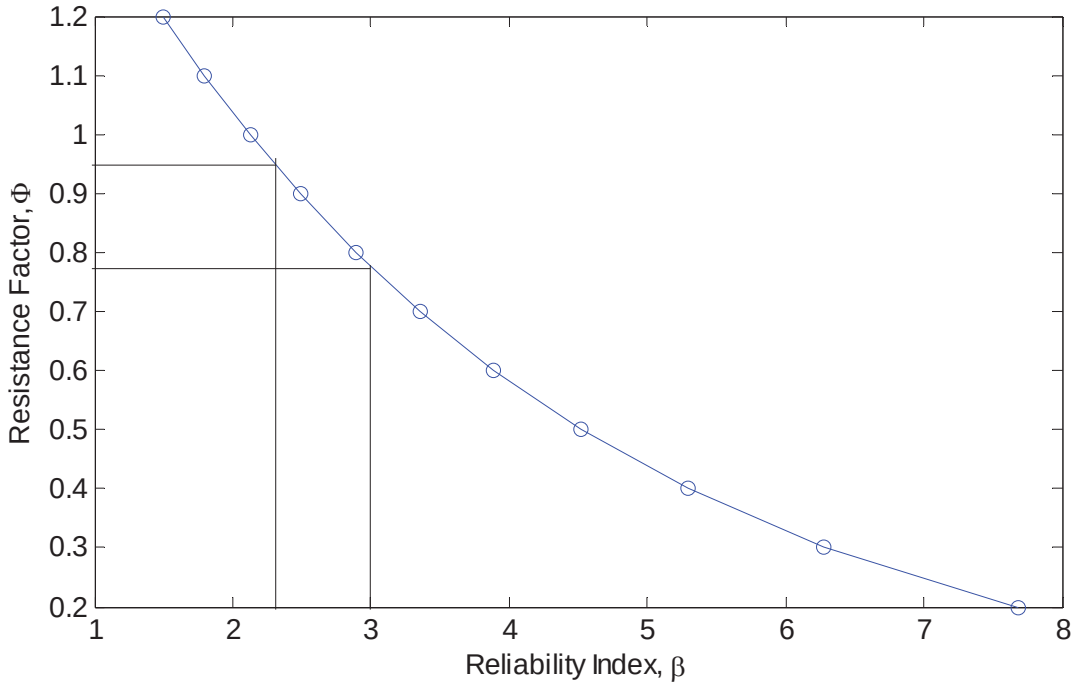


Figure F-C3-b Resistance factor calibration for 38cases of concrete piles in Clay using the α-API method (Su: Peck) in North of Vietnam

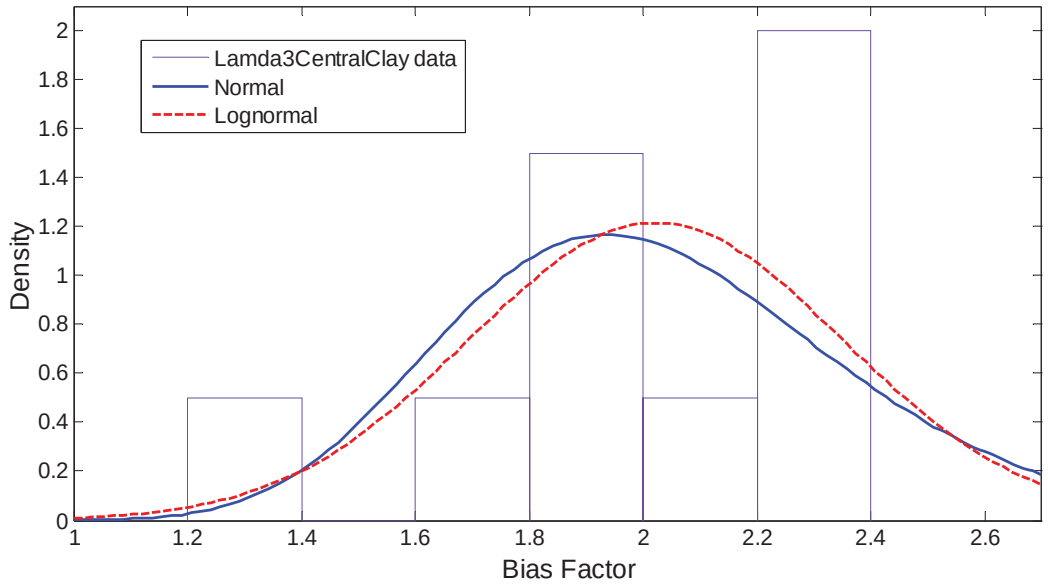


Figure F-C3-c Histogram and frequency distribution of bias factor λ3 for 10cases of concrete piles in Clay using the α-API method (Su: Peck) in Central of Vietnam

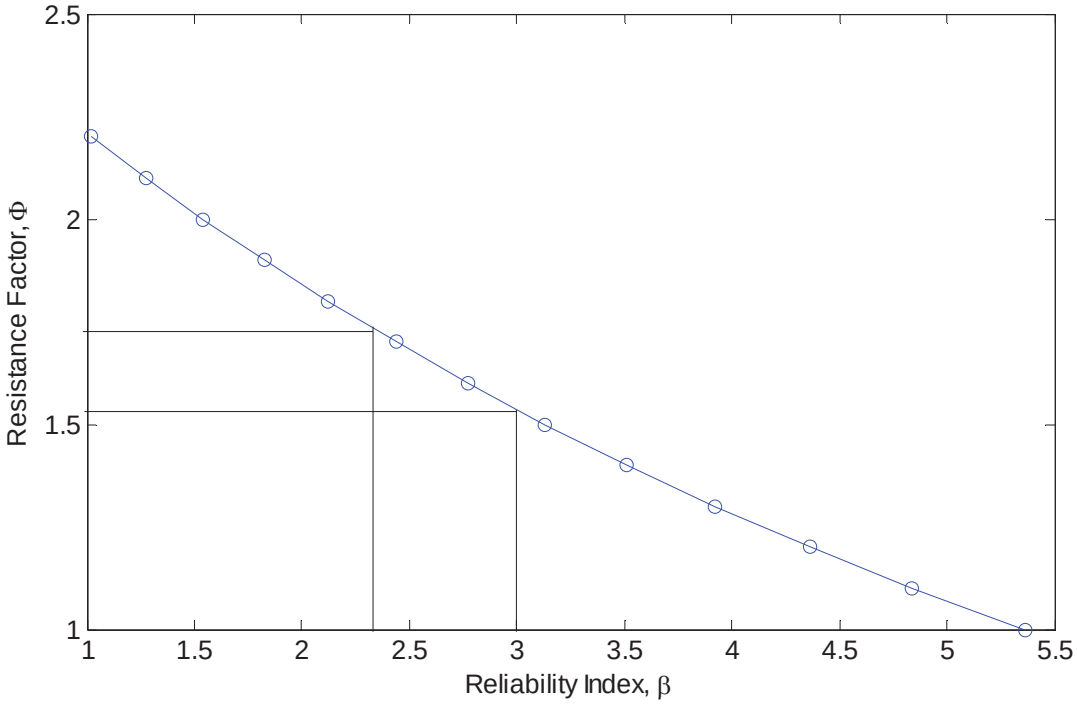


Figure F-C3-d Resistance factor calibration for 10cases of concrete piles in Clay using the α-API method (Su: Peck) in Central of Vietnam

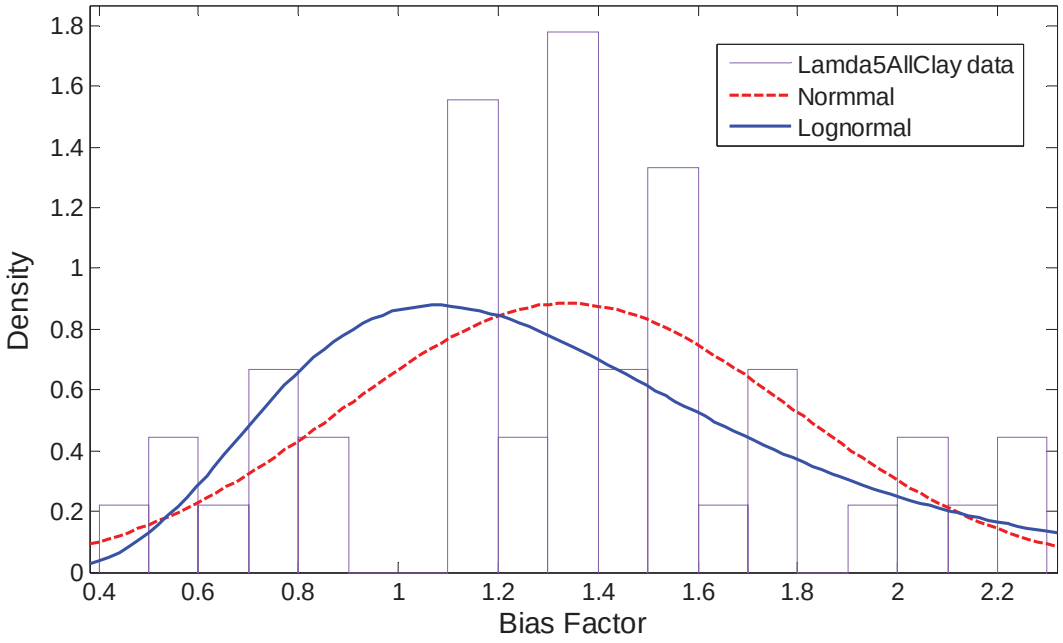


Figure F-C5-aHistogram and frequency distribution of bias factor λ5 for 50cases of concrete piles in Clay using the λmethod (Su: Peck) in Vietnam

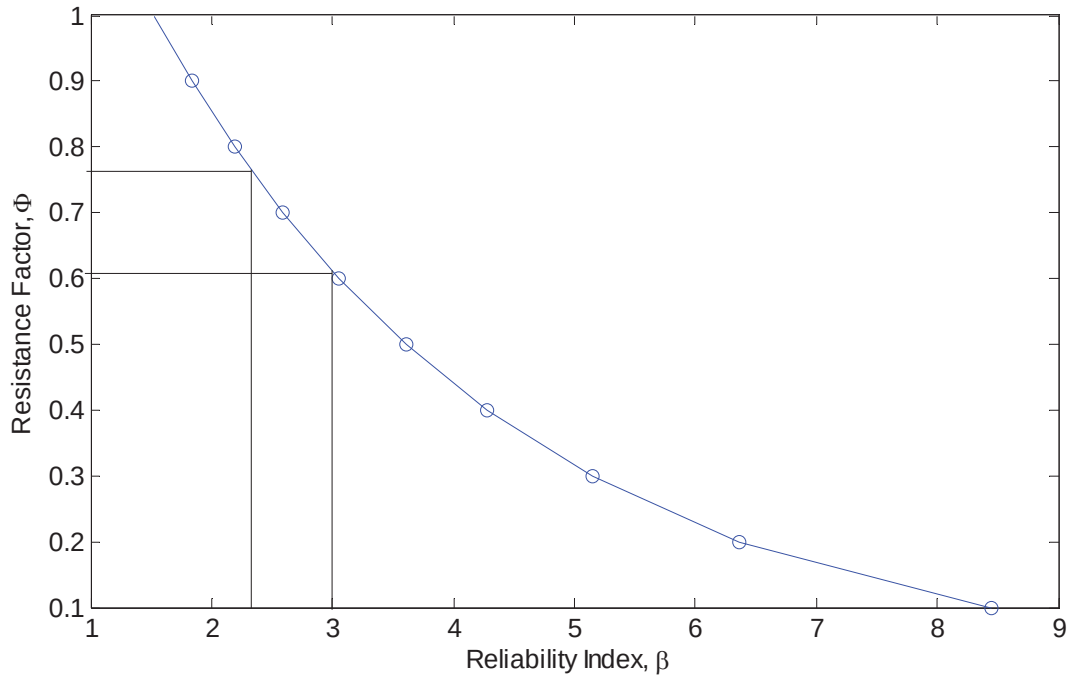


Figure F-C5-b Resistance factor calibration for 50cases of concrete piles in Clay using the λmethod (Su: Peck) in Vietnam

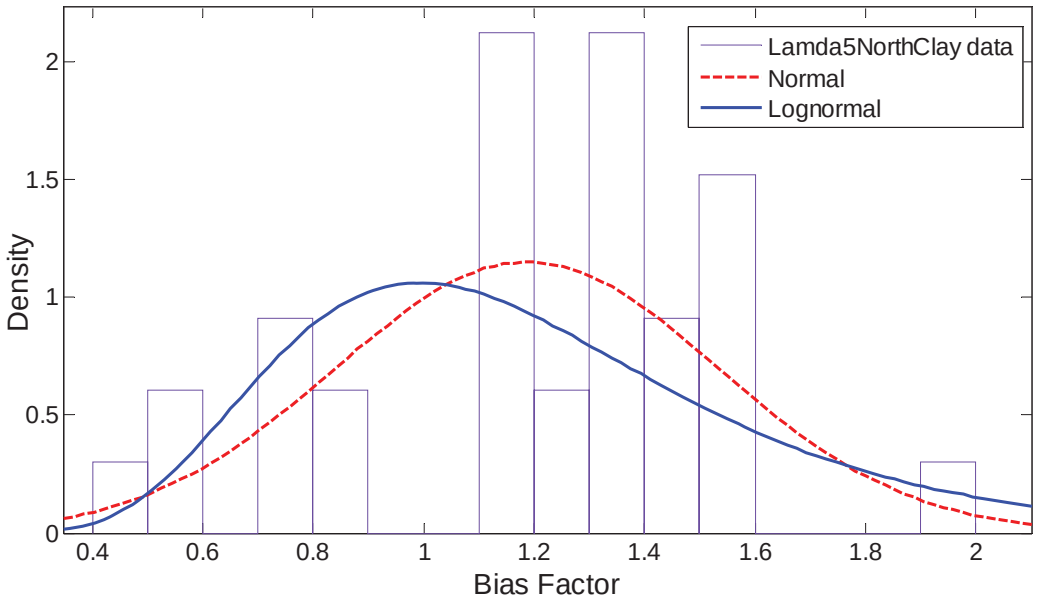


Figure F-C5-c Histogram and frequency distribution of bias factor λ5 for 38cases of concrete piles in Clay using the λmethod (Su: Peck) North of Vietnam

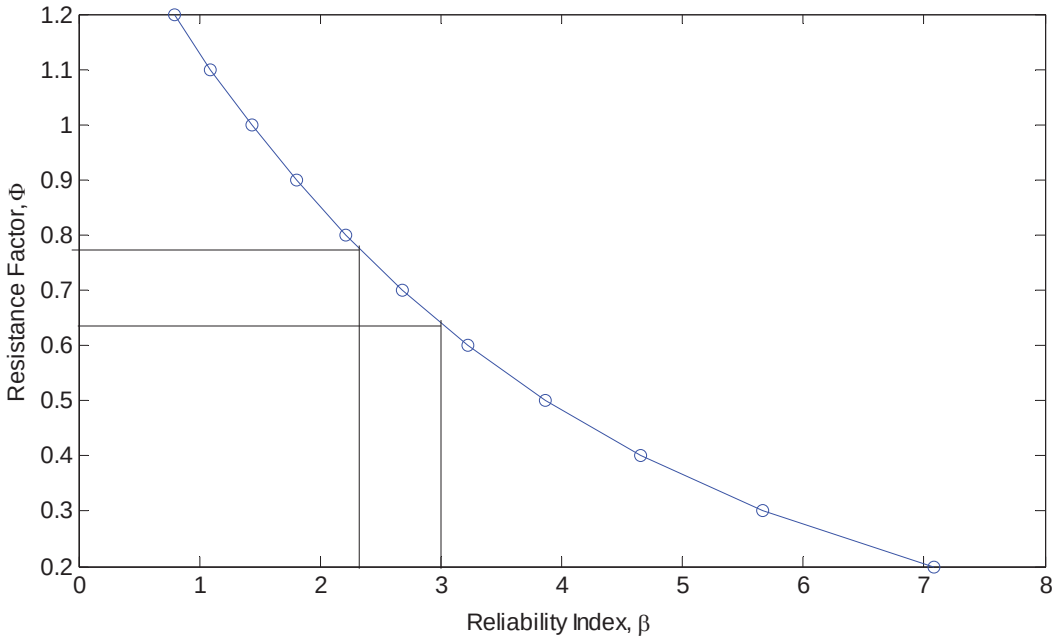


Figure F-C5-d Resistance factor calibration for 38cases of concrete piles in Clay using the λmethod (Su: Peck) North of Vietnam

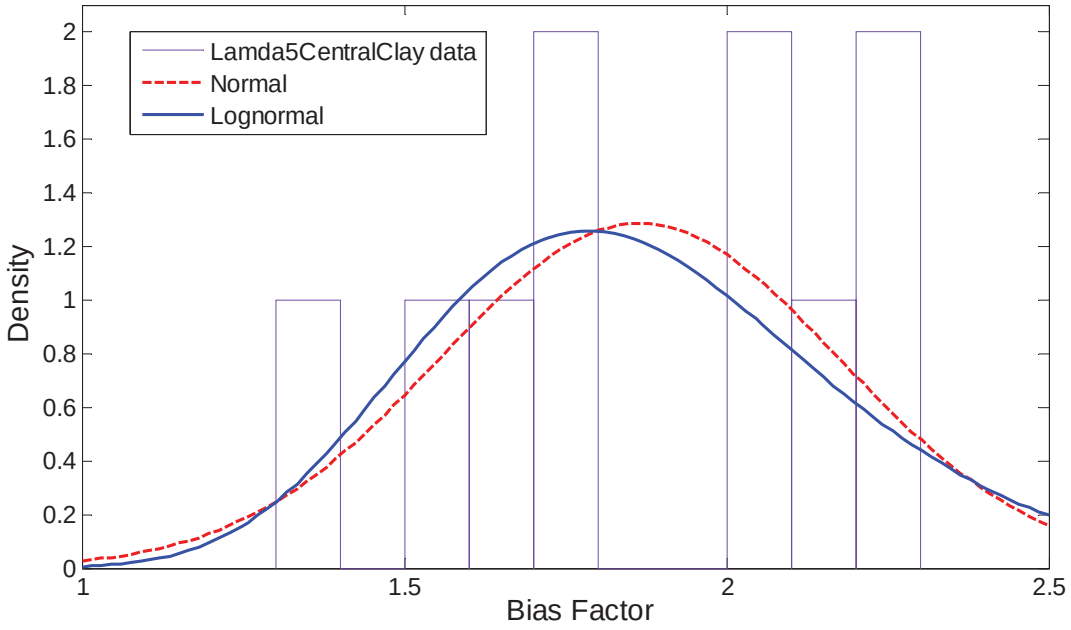


Figure F-C5-e Histogram and frequency distribution of bias factor λ5 for 10cases of concrete piles in Clay using the λmethod (Su: Peck) Central of Vietnam

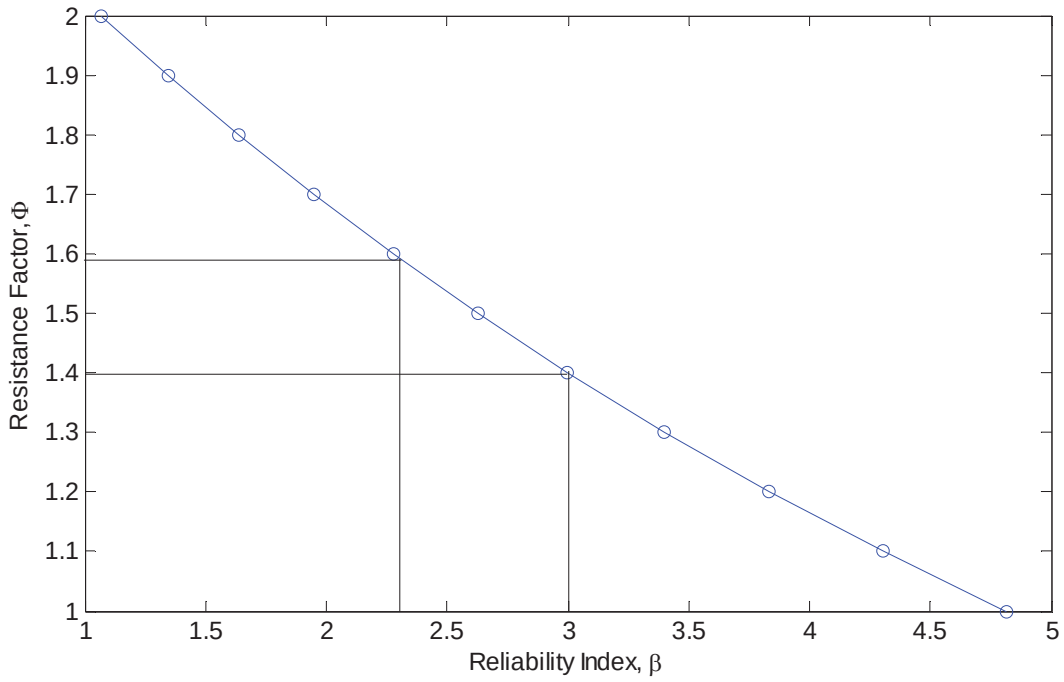


Figure F-C5-f Resistance factor calibration for 10cases of concrete piles in Clay using the λmethod (Su: Peck) Central of Vietnam

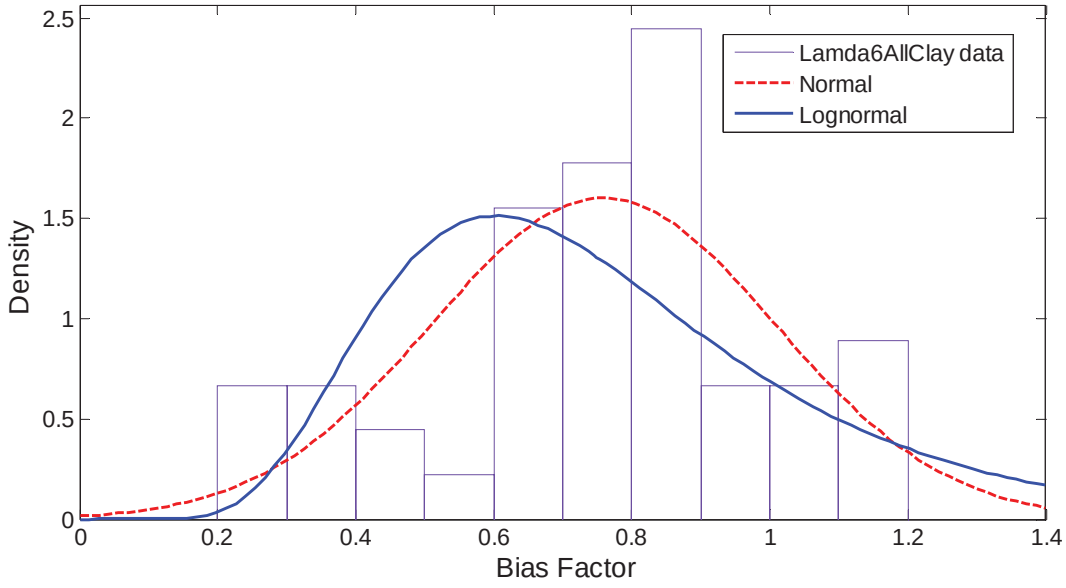


Figure F-C6-a Histogram and frequency distribution of bias factor λ6 for 50cases of concrete piles in Clay using the λmethod (Su: Hara) in Vietnam

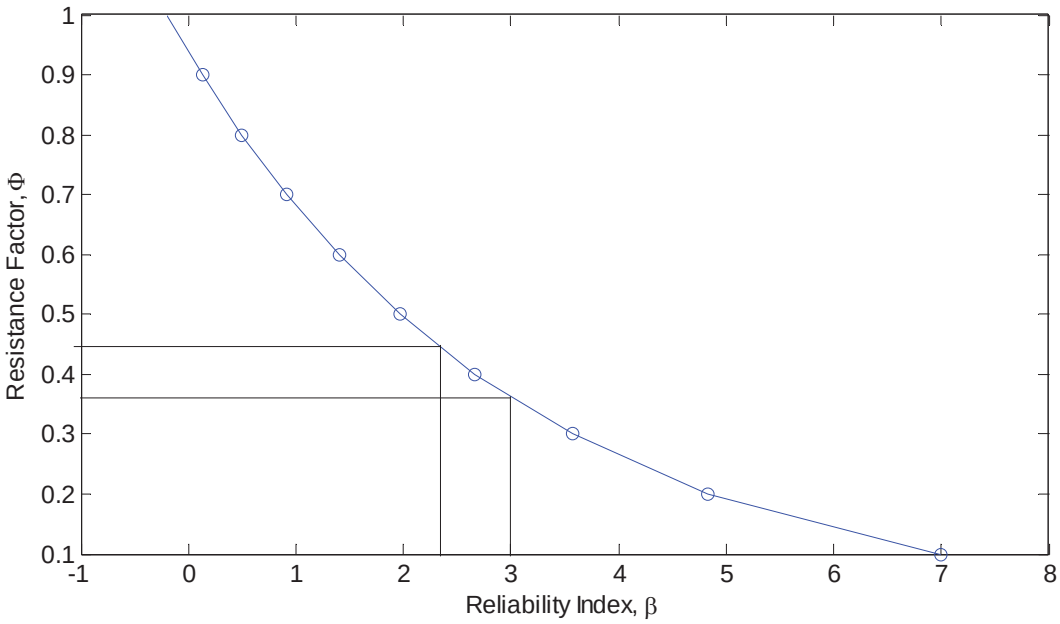


Figure F-C6-b Resistance factor calibration for 50cases of concrete piles in Clay using the λmethod (Su: Hara) in Vietnam

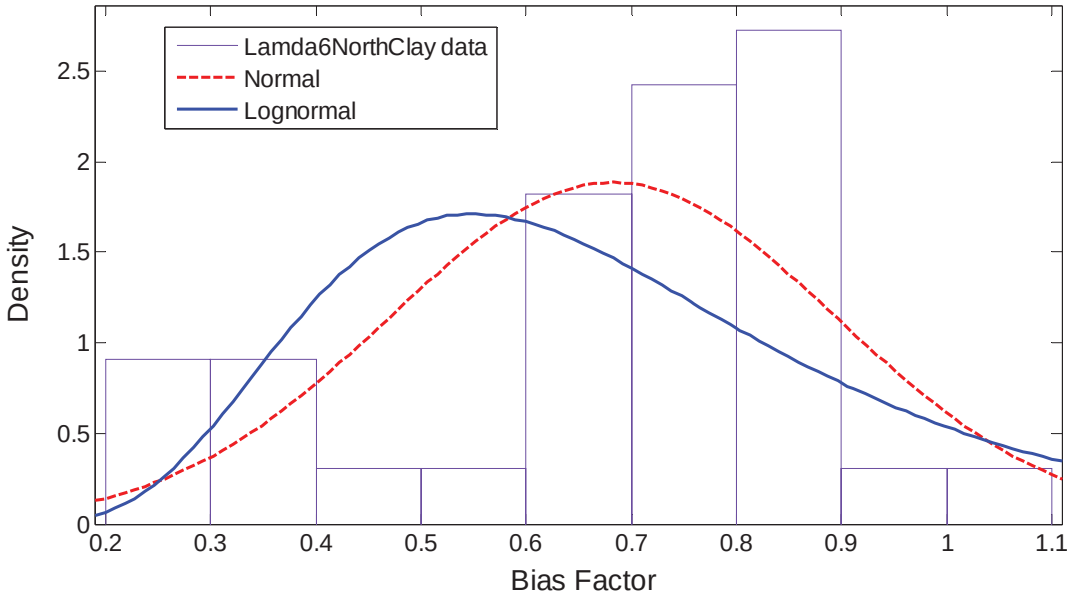


Figure F-C6-cHistogram and frequency distribution of bias factor λ6 for 38cases of concrete piles in Clay using the λmethod (Su: Hara) in North of Vietnam

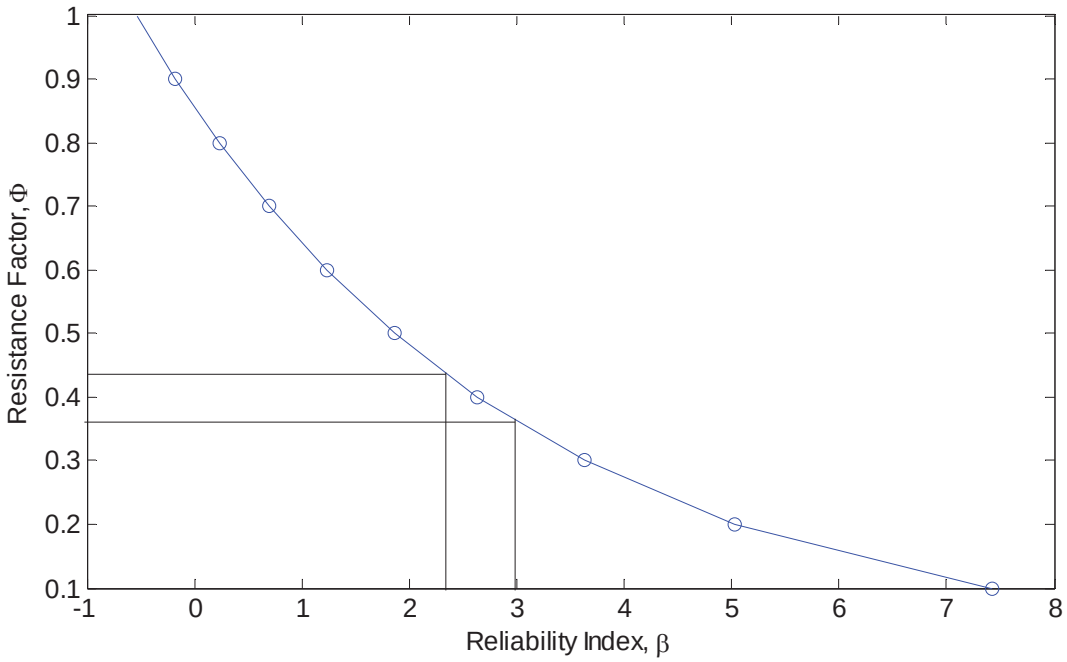


Figure F-C6-d Resistance factor calibration for 38cases of concrete piles in Clay using the λmethod (Su: Hara) in North of Vietnam

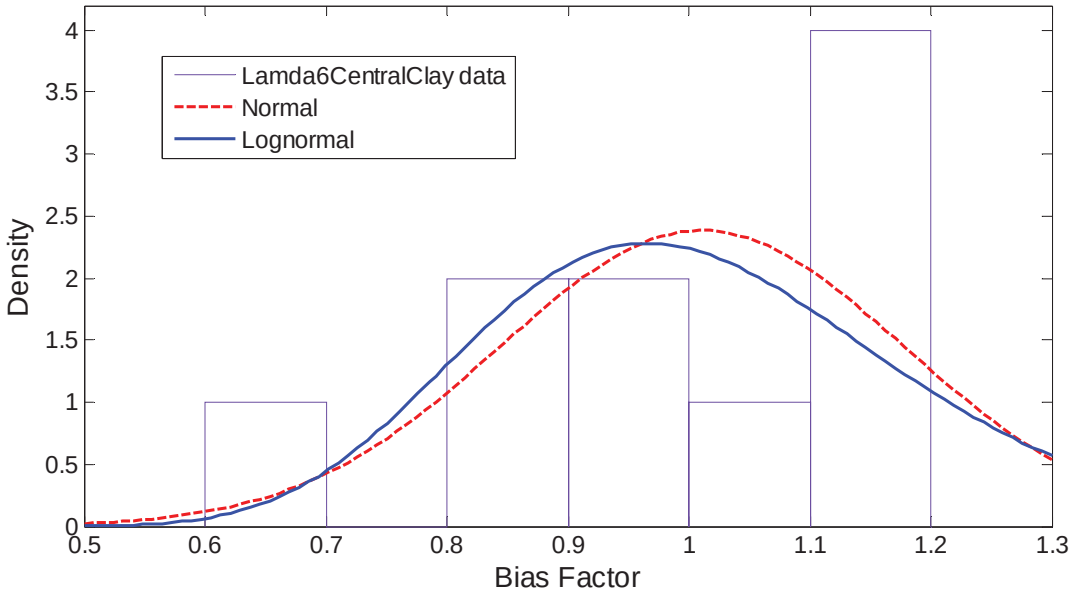


Figure F-C6-eHistogram and frequency distribution of bias factor λ6 for 10cases of concrete piles in Clay using the λmethod (Su: Hara) in South of Vietnam

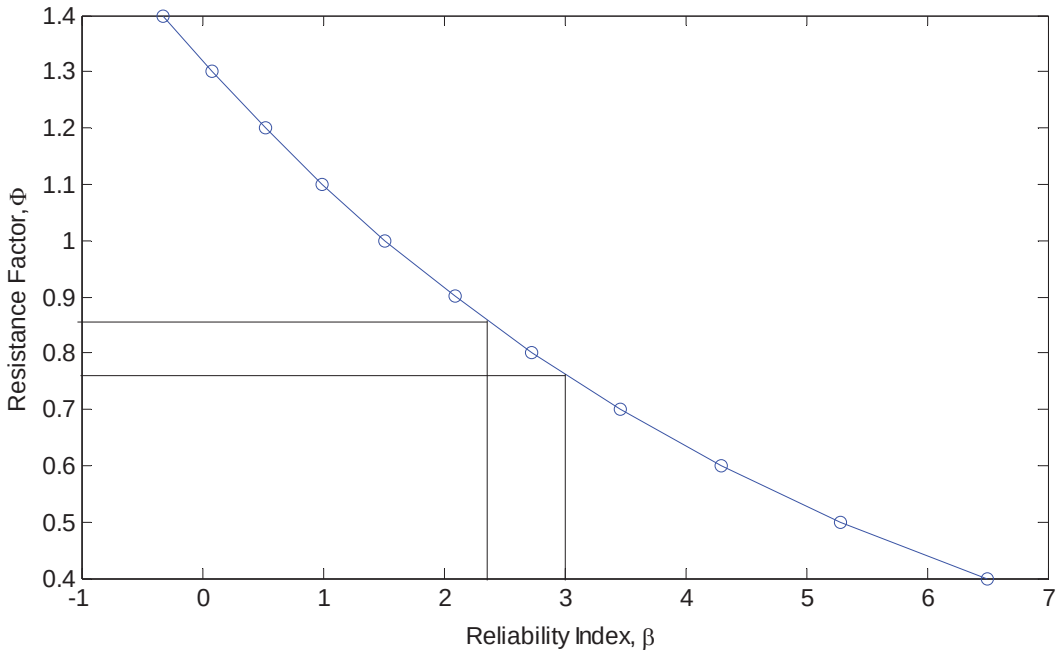


Figure F-C6-f Resistance factor calibration for 10cases of concrete piles in Clay using the λmethod (Su: Hara) in South of Vietnam

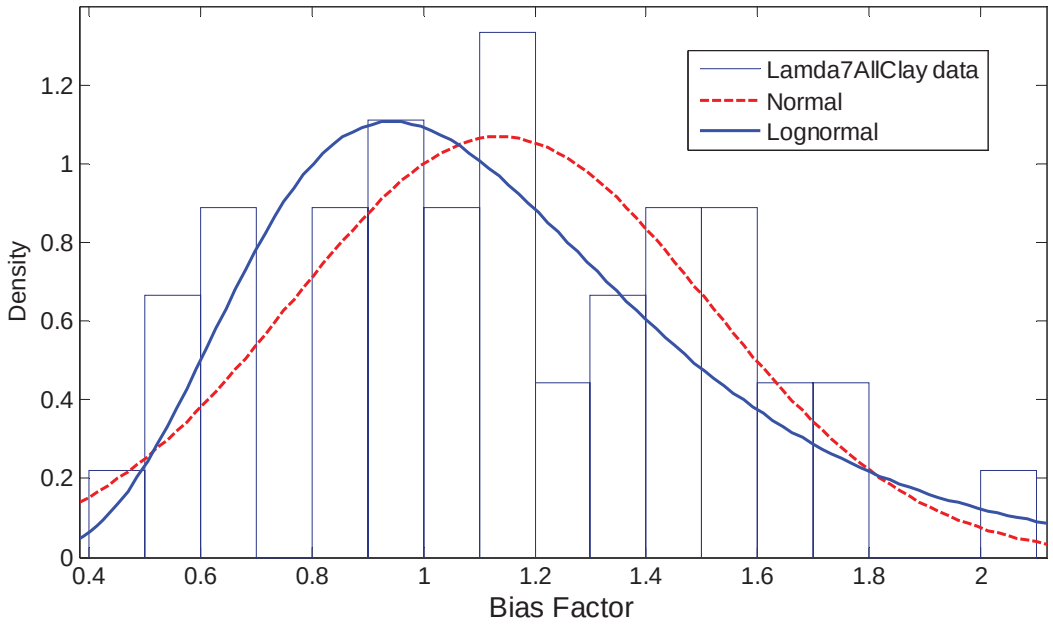


Figure F-C7-aHistogram and frequency distribution of bias factor λ7 for 50 cases of concrete piles in Clay using the β methodin Vietnam

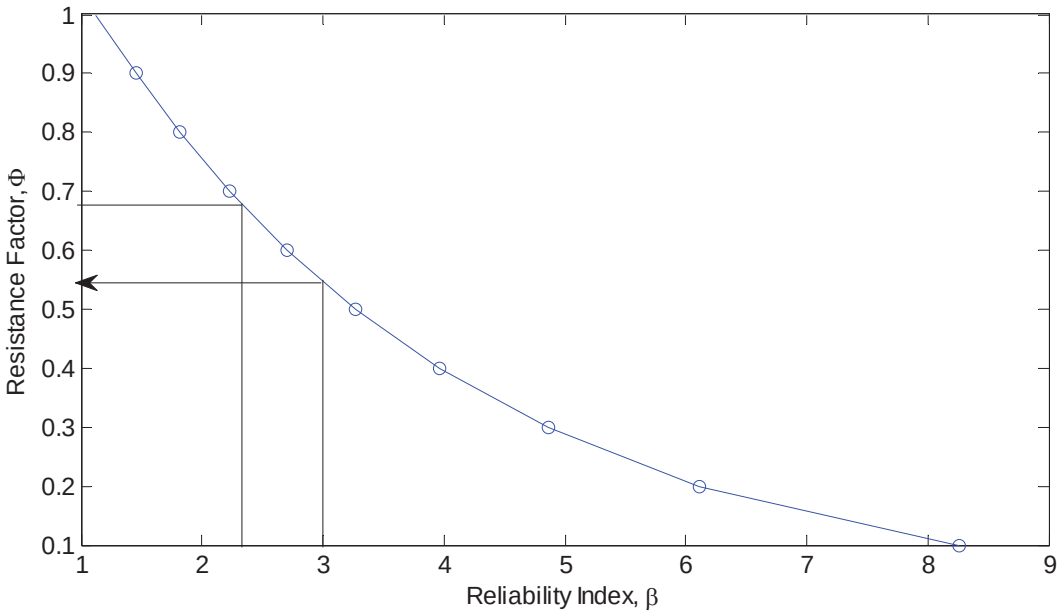


Figure F-C7-bResistance factor calibration of concrete piles in Clay using the β methodin Vietnam

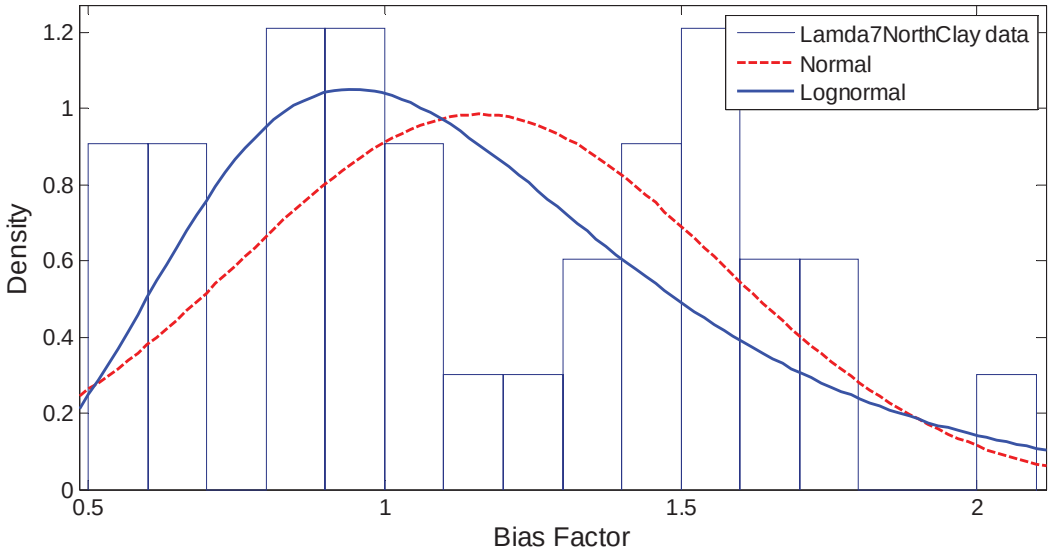


Figure F-C7-cHistogram and frequency distribution of bias factor λ7 for 38cases of concrete piles in Clay using the βmethod in North of Vietnam

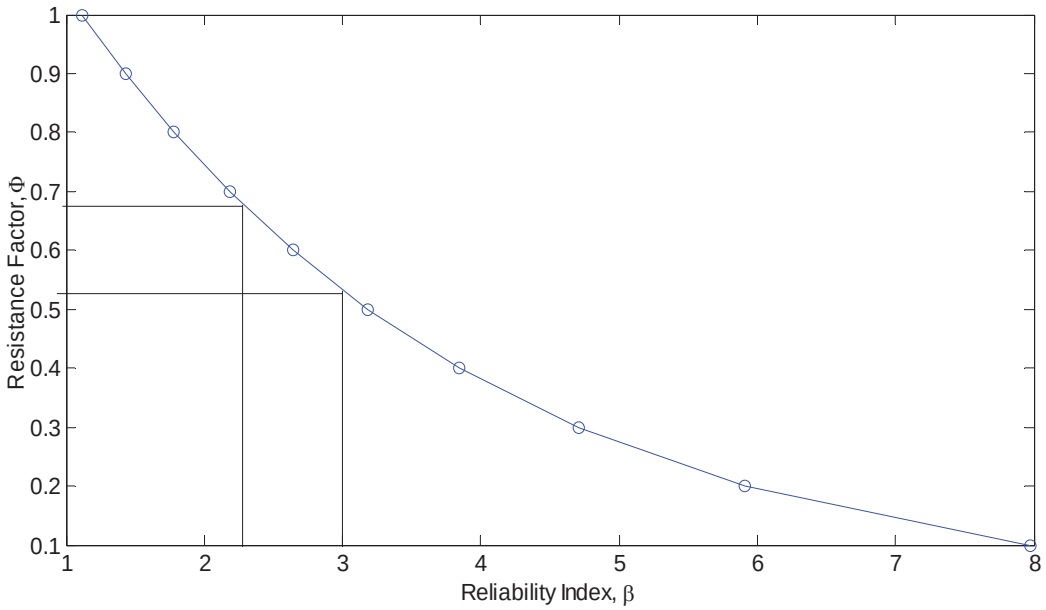


Figure F-C7-dResistance factor calibration of concrete piles in Clay using the βmethod in North of Vietnam

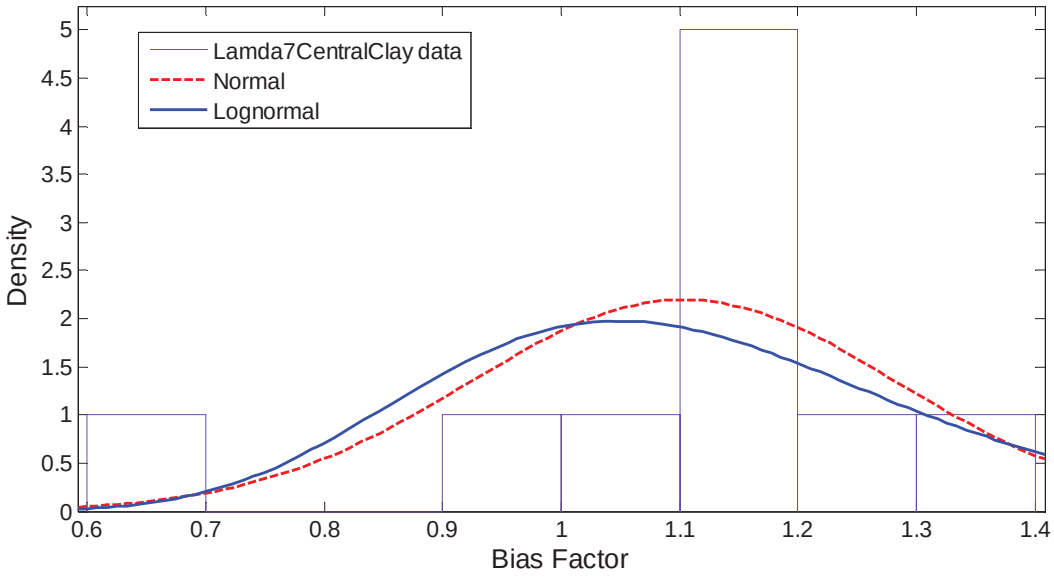


Figure F-C7-eHistogram and frequency distribution of bias factor λ7 for 10cases of concrete piles in Clay using the βmethod in Central of Vietnam

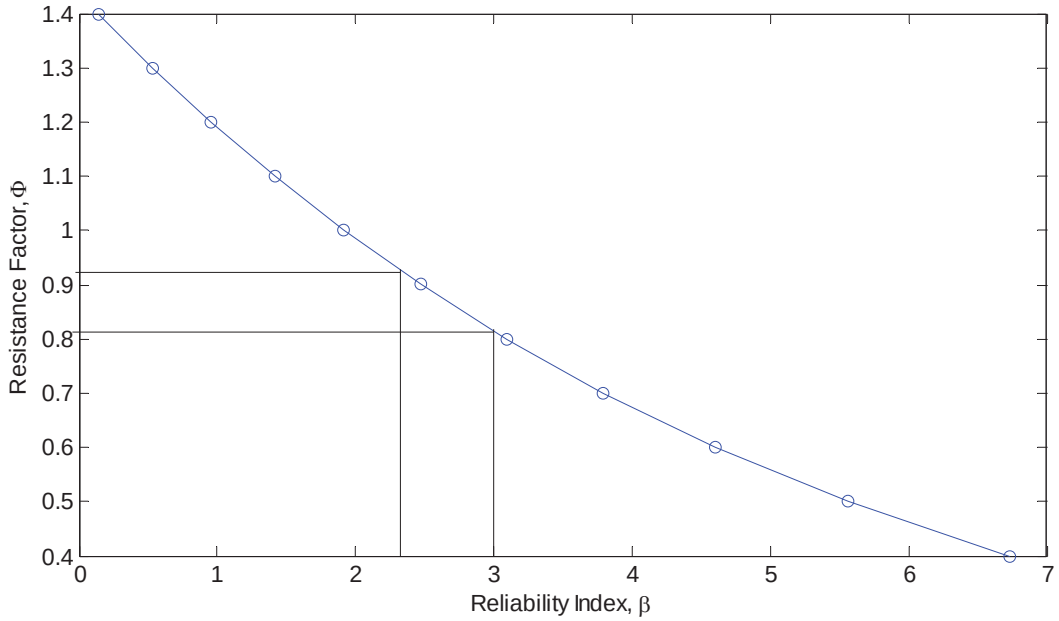


Figure F-C7-fResistance factor calibration of concrete piles in Clay using the βmethod in Central of Vietnam

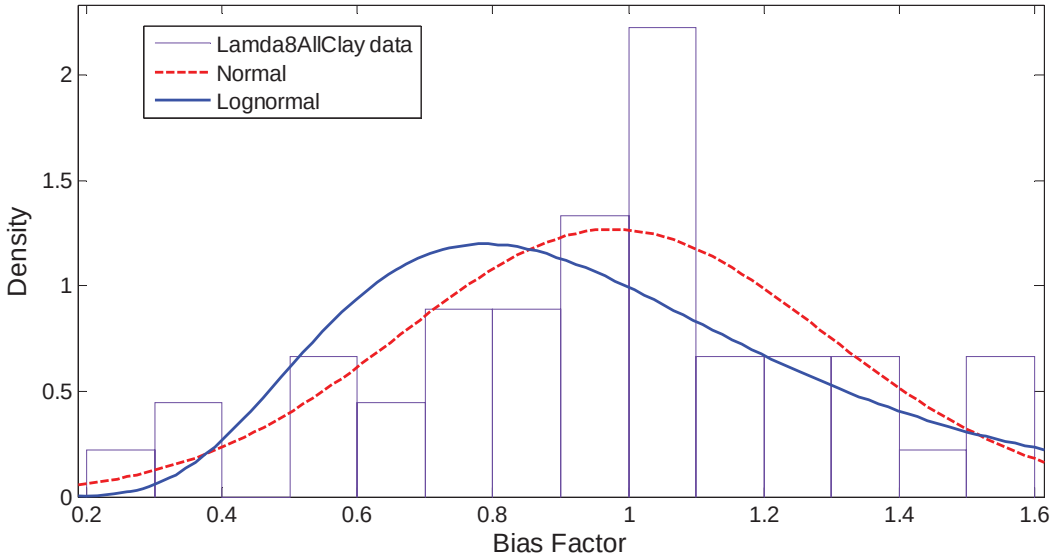


Figure F-C8-a Histogram and frequency distribution of bias factor λ8 for 50 cases of concrete piles in Clay using the Schmertmann SPT in Vietnam

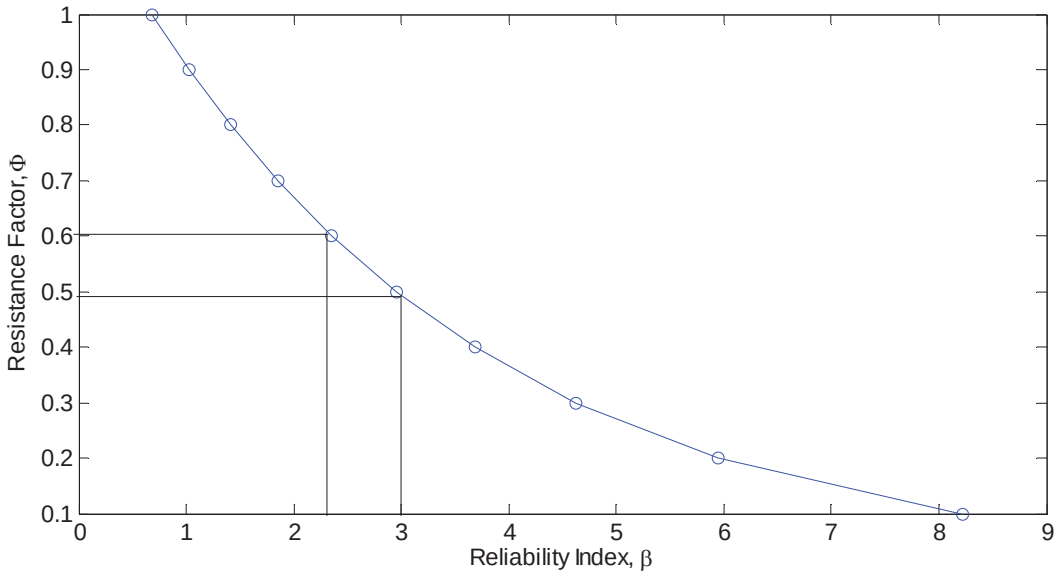


Figure F-C8-bResistance factor calibration for 50 cases of concrete piles in Clay using the Schmertmann SPT in Vietnam

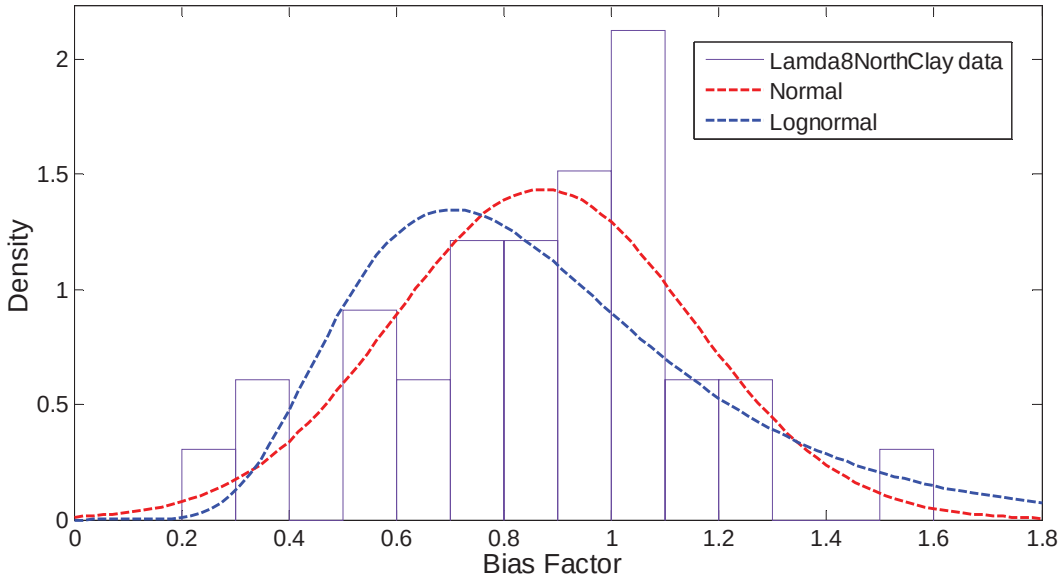


Figure F-C8-cHistogram and frequency distribution of bias factor λ8 for 38 cases of concrete piles in Clay using the Schmertmann SPT in North of Vietnam

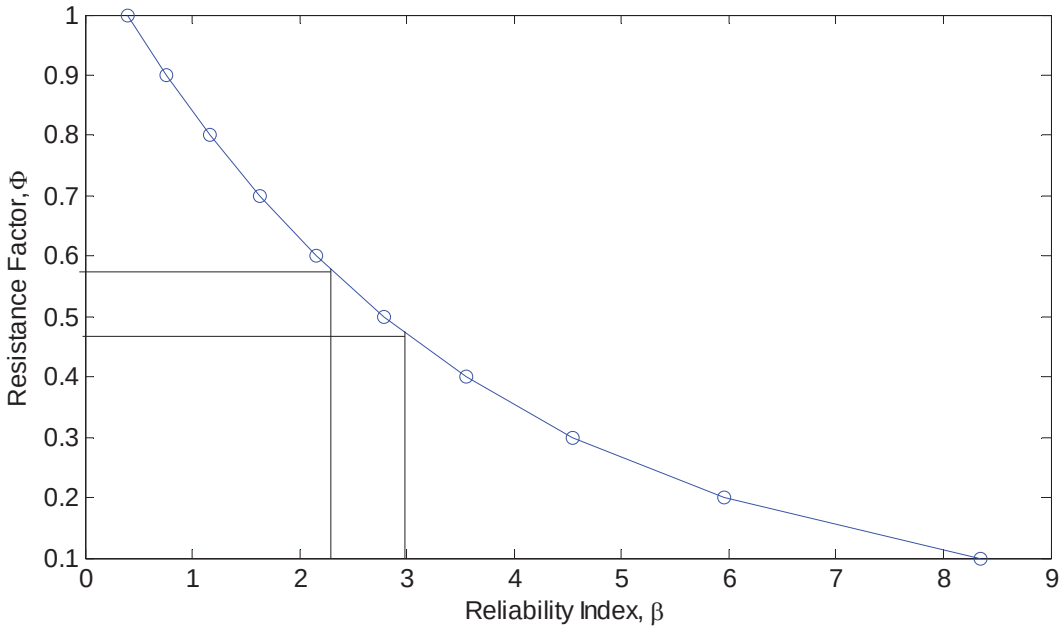


Figure F-C8-dResistance factor calibrationfor 38 cases of concrete piles in Clay using the Schmertmann SPT in North of Vietnam

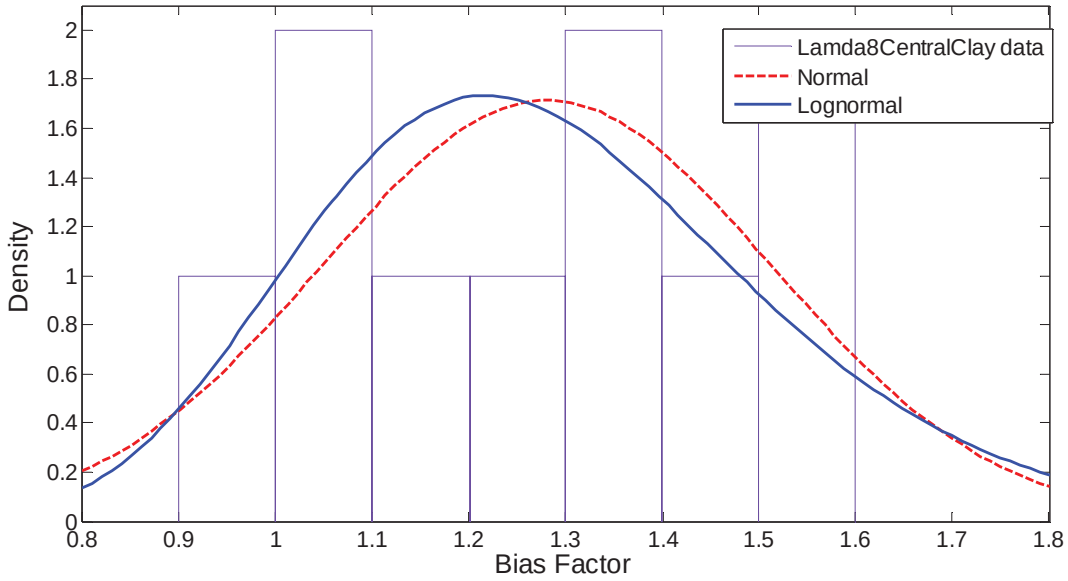


Figure F-C8-eHistogram and frequency distribution of bias factor λ8 for 10 cases of concrete piles in Clay using the Schmertmann SPT in South of Vietnam

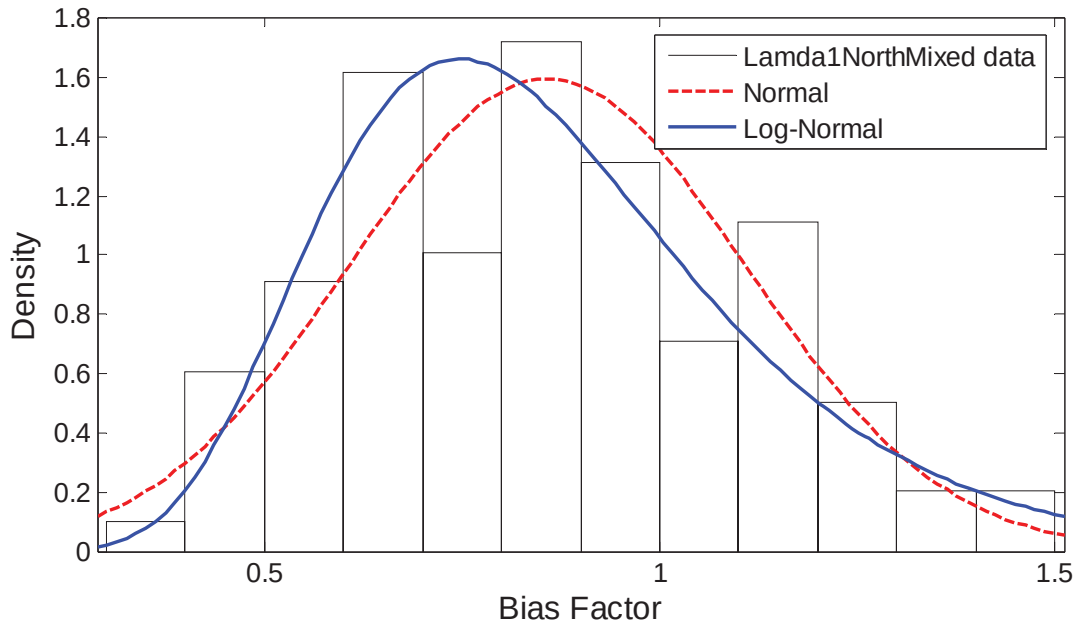


Figure F-M1-a Histogram and frequency distribution of bias factor λ1 for 165 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Vietnam

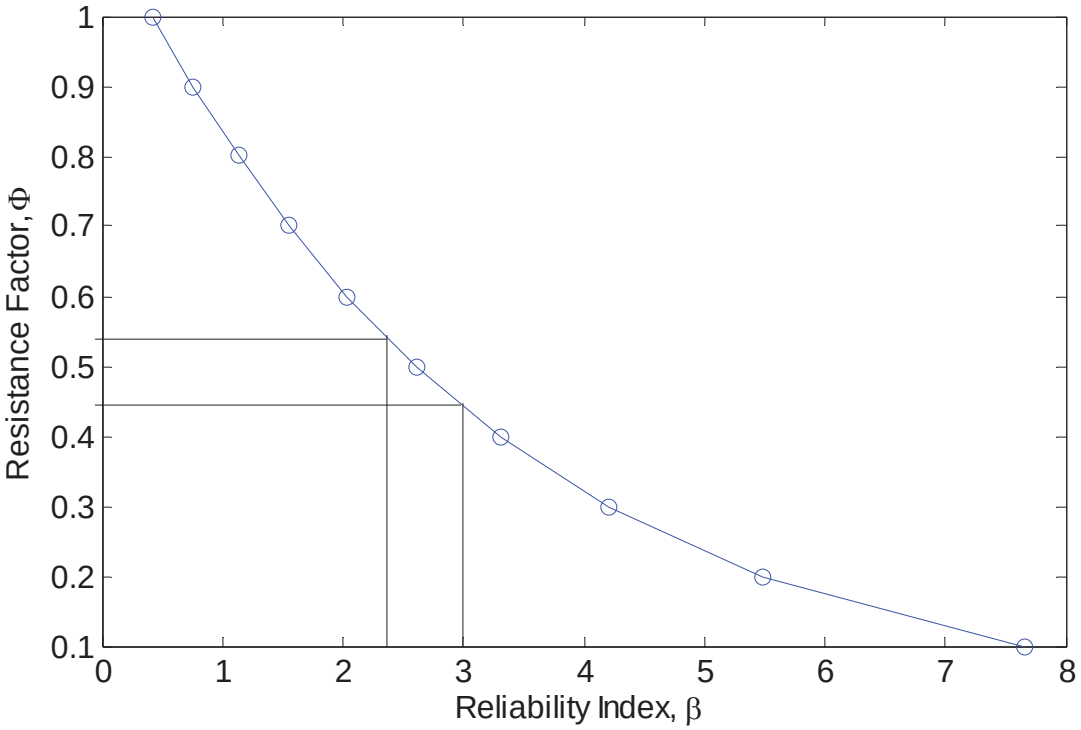


Figure F-M1-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Vietnam

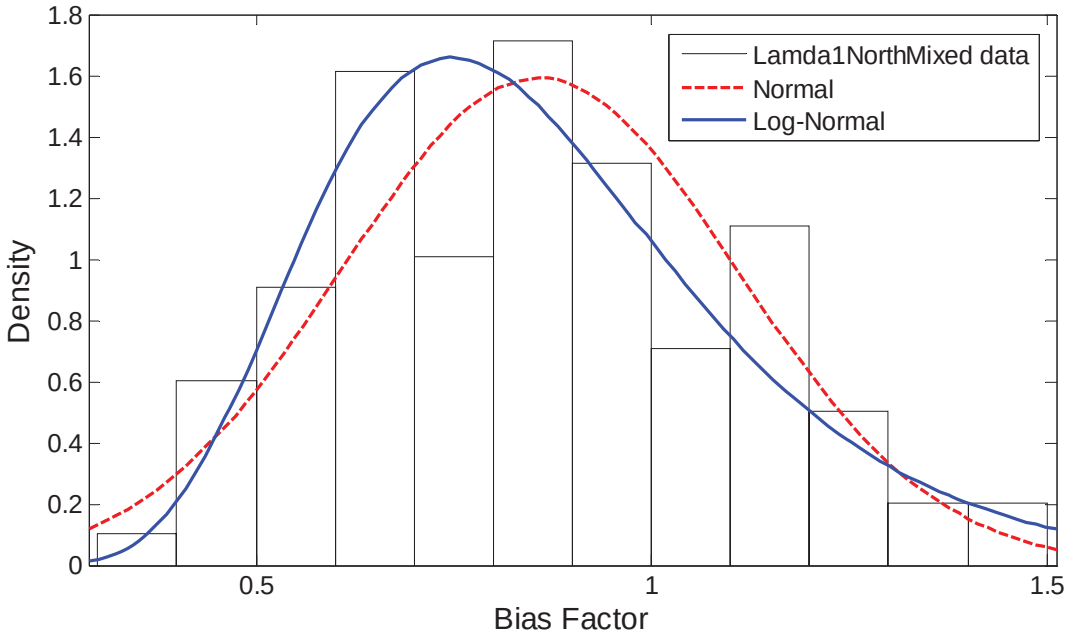


Figure F-M1-cHistogram and frequency distribution of bias factor λ1 for 99 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

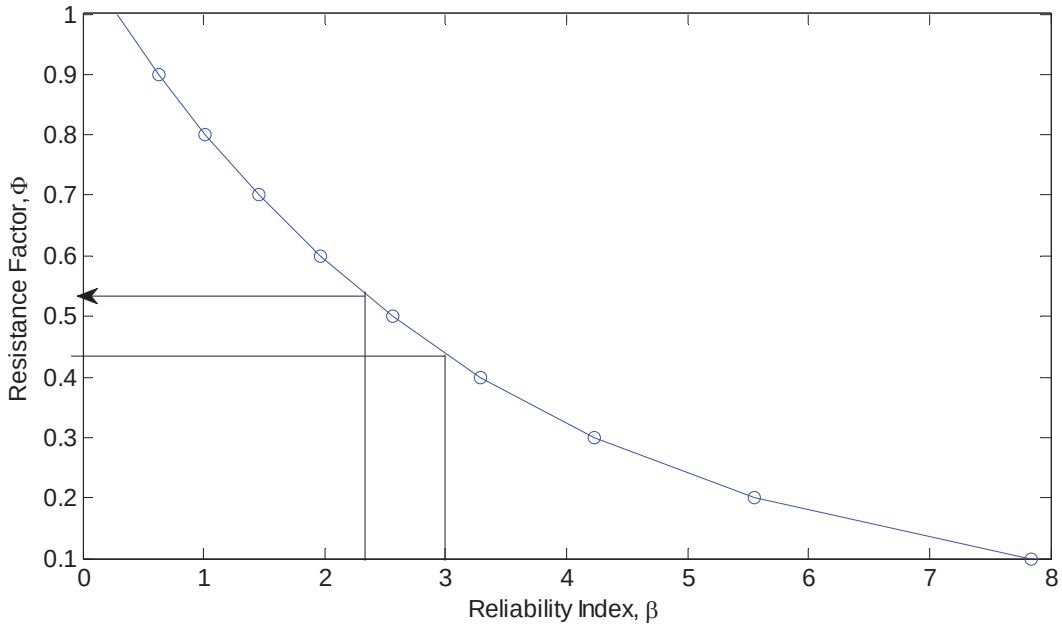


Figure F-M1-dResistance factor calibration for 99 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

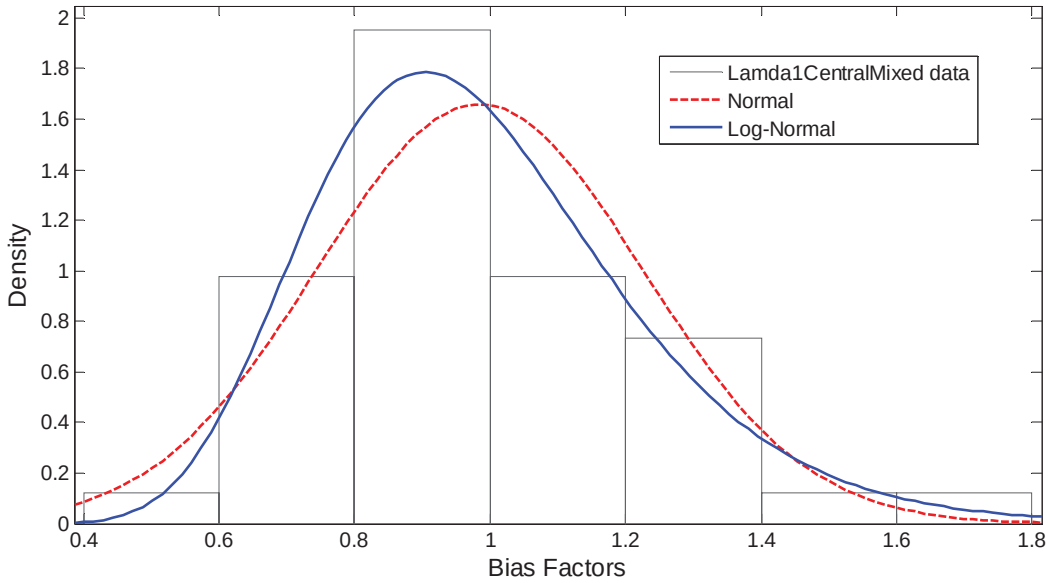


Figure F-M1-e Histogram and frequency distribution of bias factor λ1 for 41cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

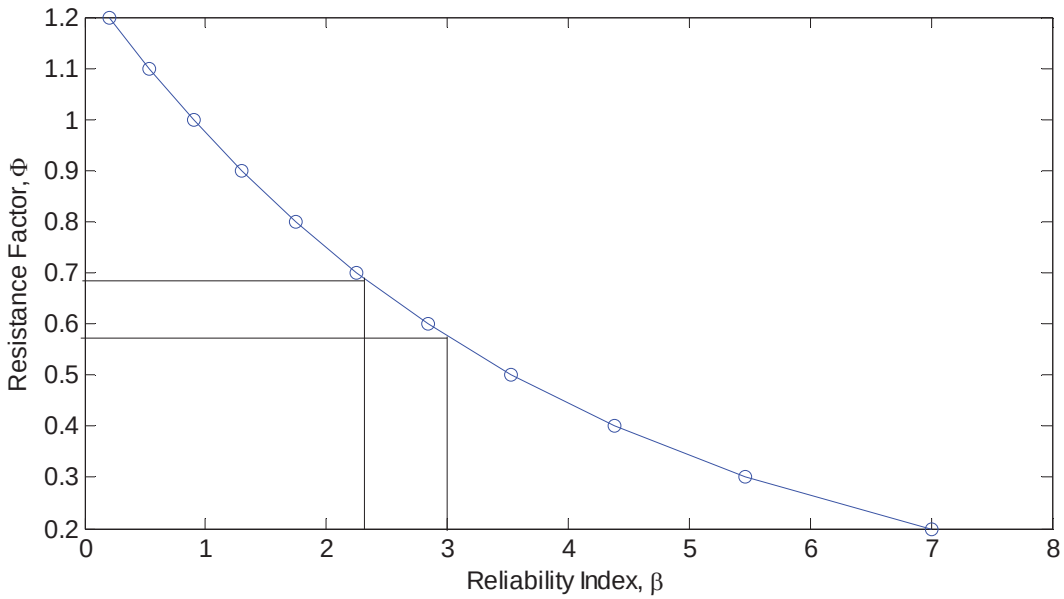


Figure F-M1-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

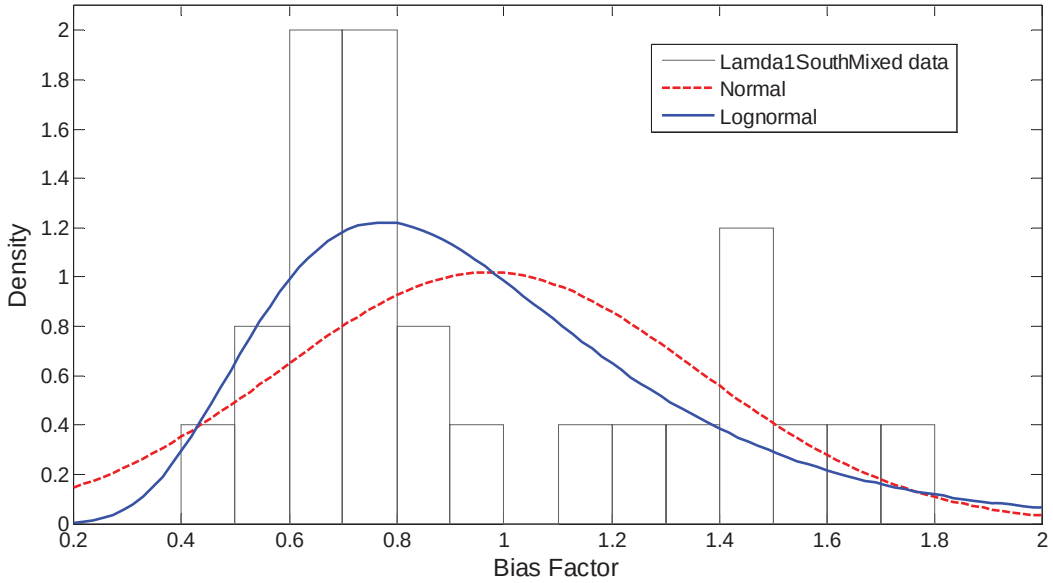


Figure F-M1-gHistogram and frequency distribution of bias factor λ1 for 25cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

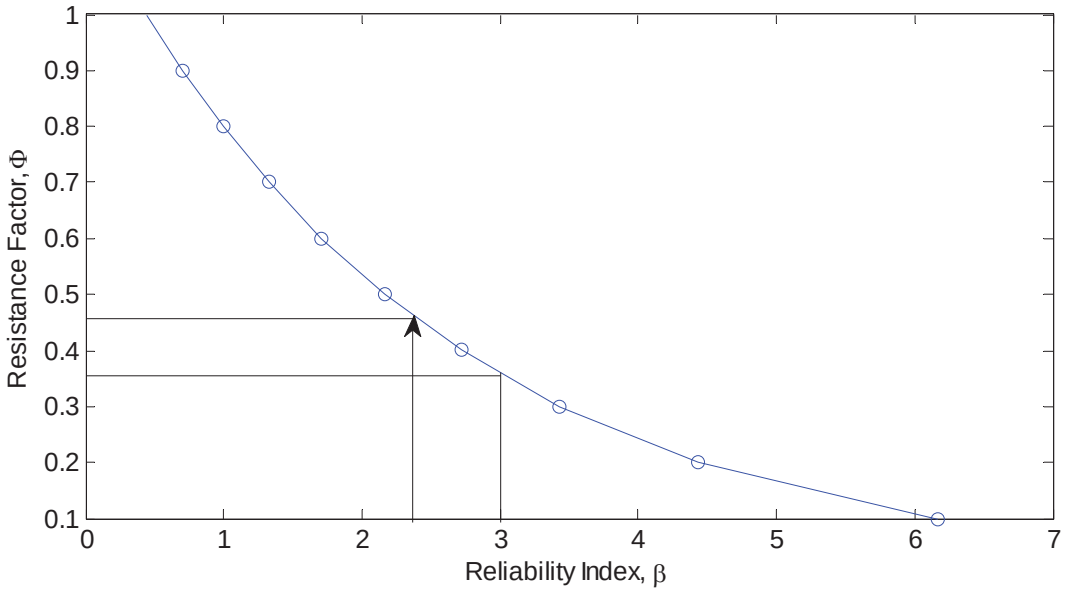


Figure F-M1-hResistance factor calibration for 25cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

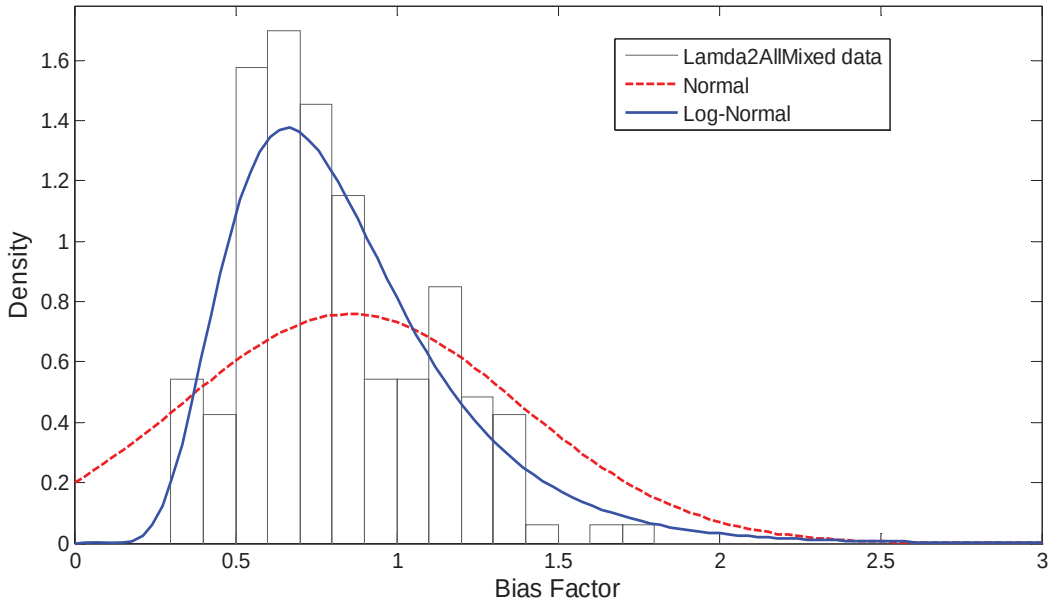


Figure F-M2-aHistogram and frequency distribution of bias factor λ2 for 165cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Vietnam

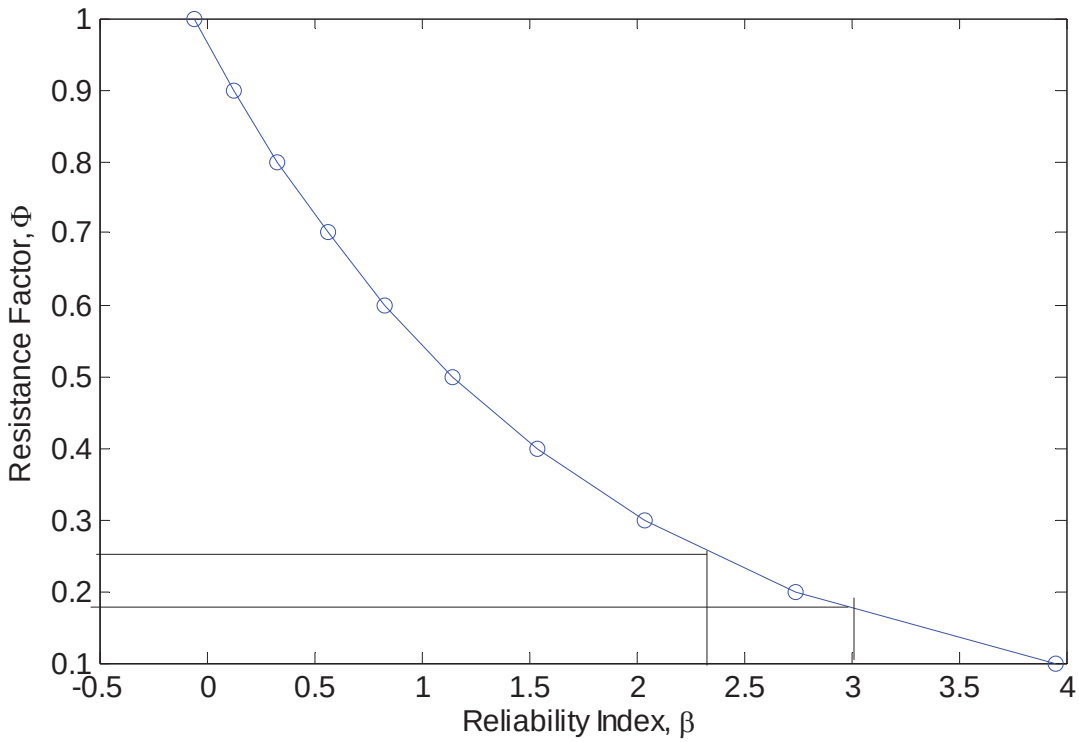


Figure F-M2-bResistance factor calibration for 165cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Vietnam

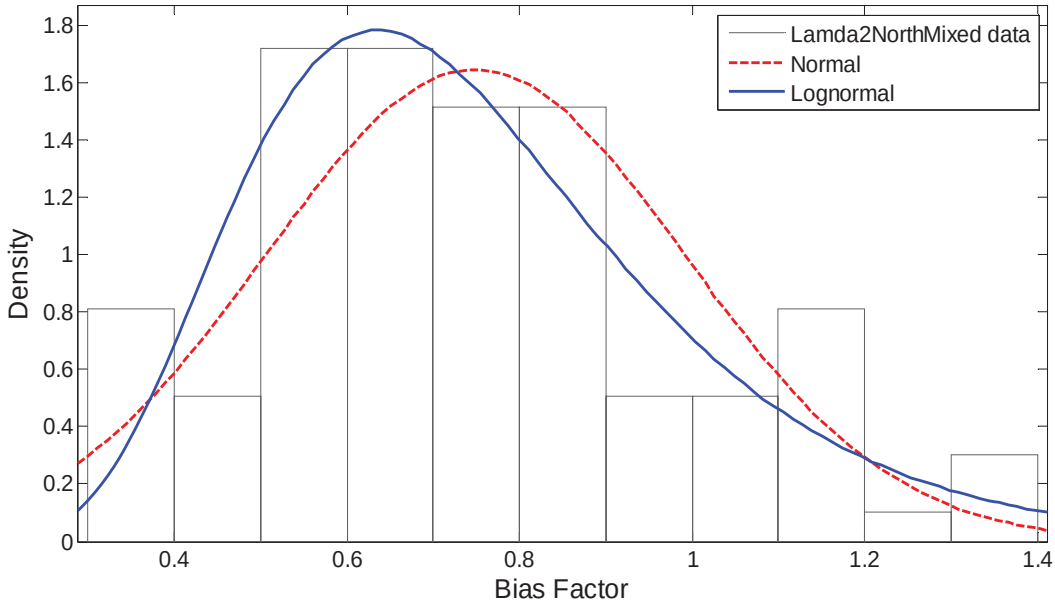


Figure F-M2-cHistogram and frequency distribution of bias factor λ2 for 99cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

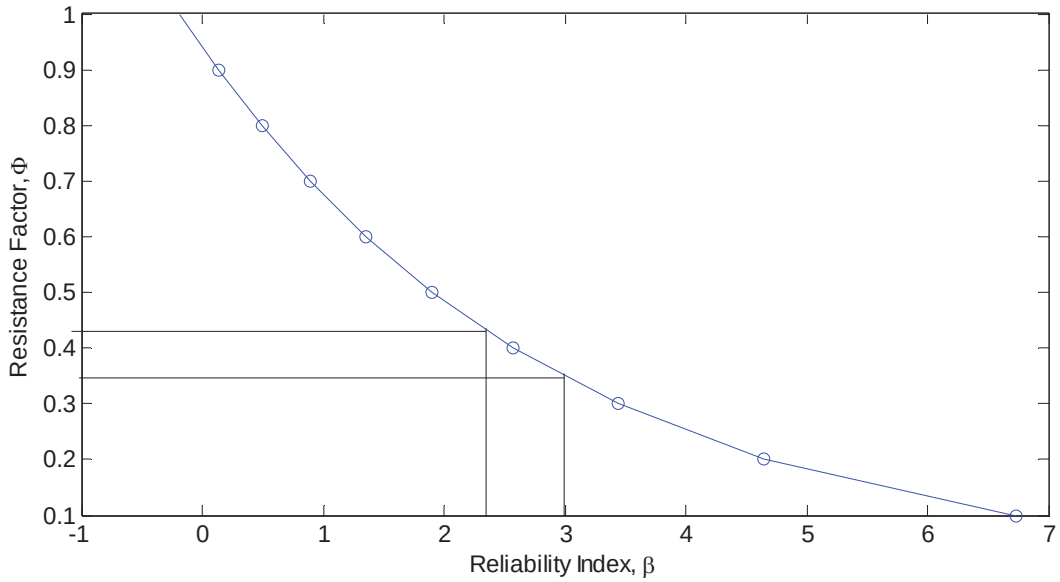


Figure F-M2-dResistance factor calibration for 99cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

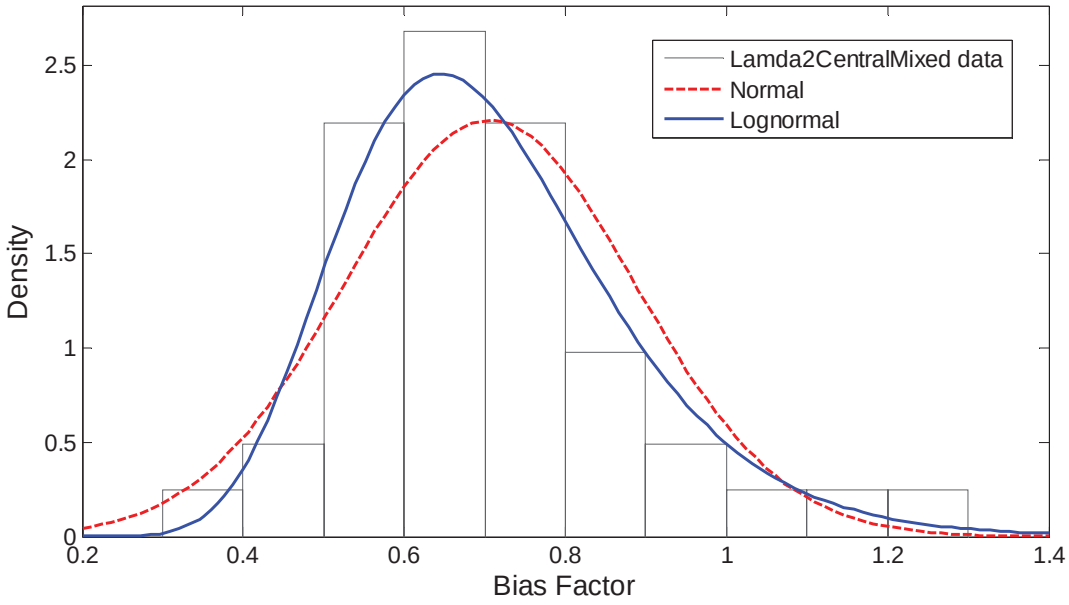


Figure F-M2-eHistogram and frequency distribution of bias factor λ2 for 41 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

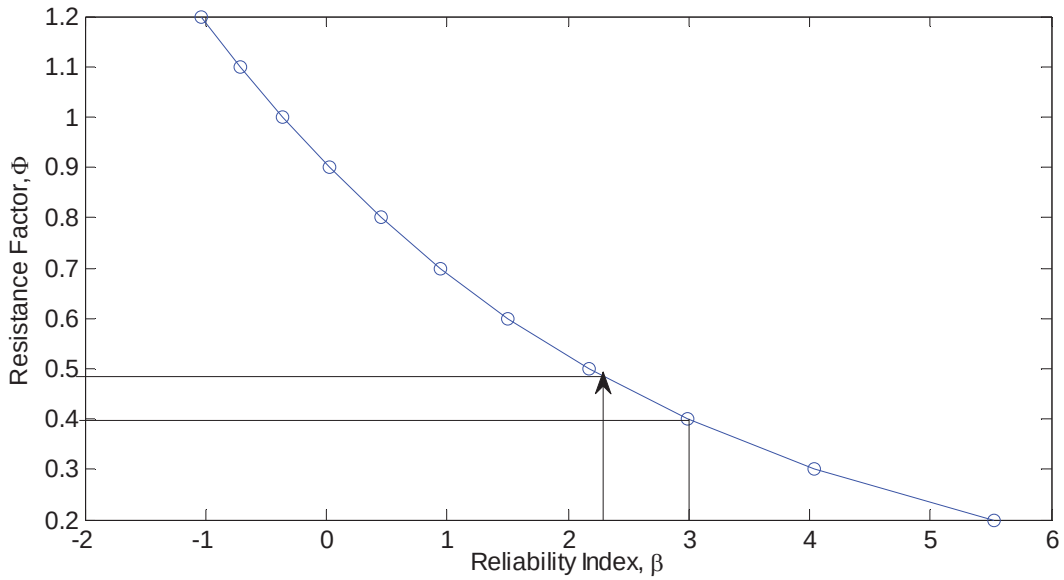


Figure F-M2-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

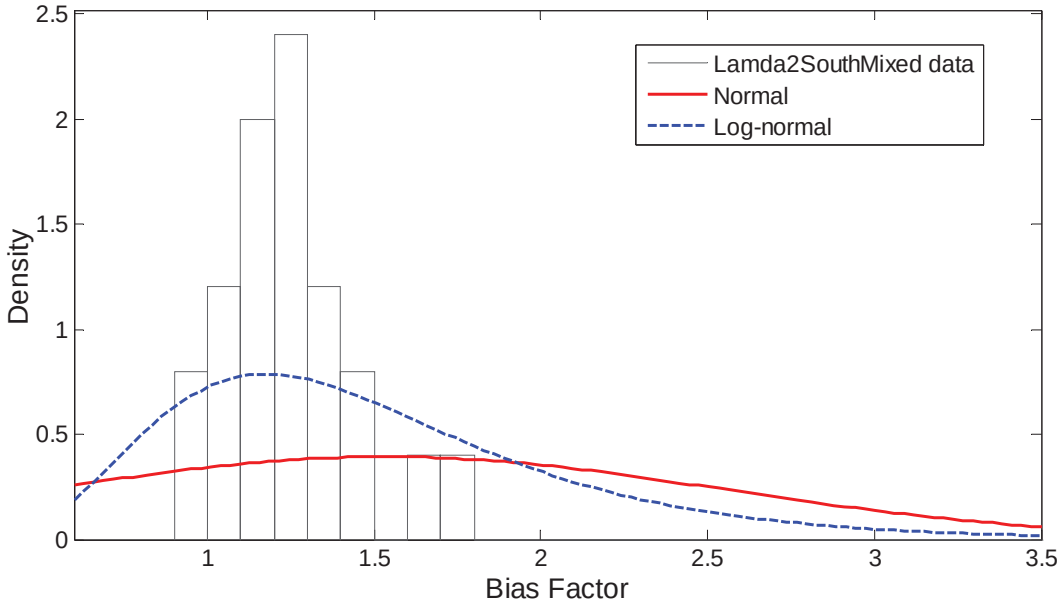


Figure F-M2-g Histogram and frequency distribution of bias factor λ2 for 25 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

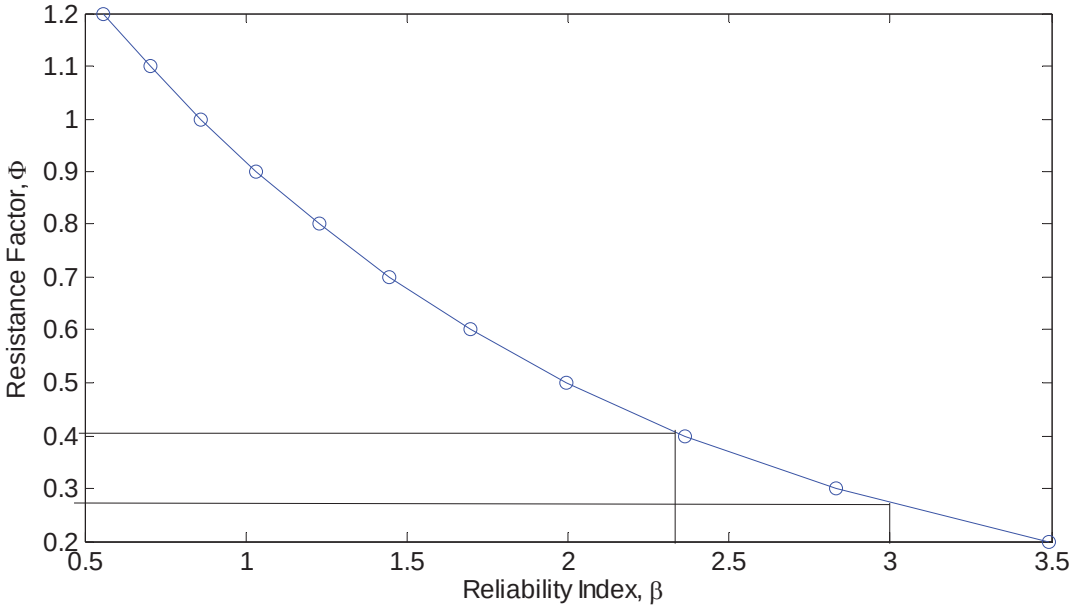


Figure F-M2-hResistance factor calibration for 25cases of concrete piles in Mixed soils using the α-Tomlinson and Nordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

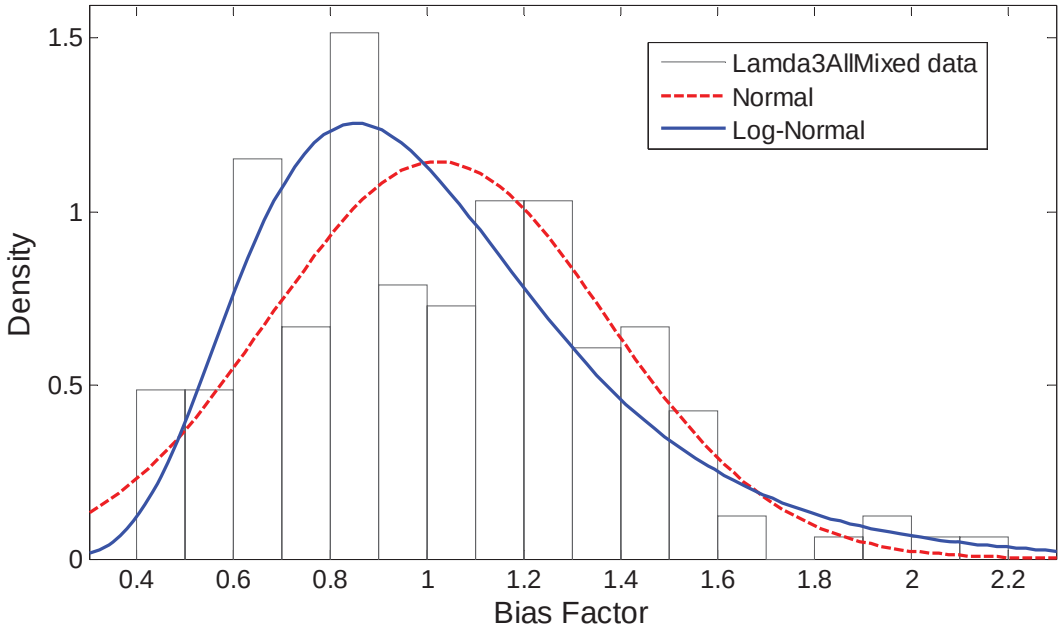


Figure F-M3-aHistogram and frequency distribution of bias factor λ3 for 165 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Vietnam

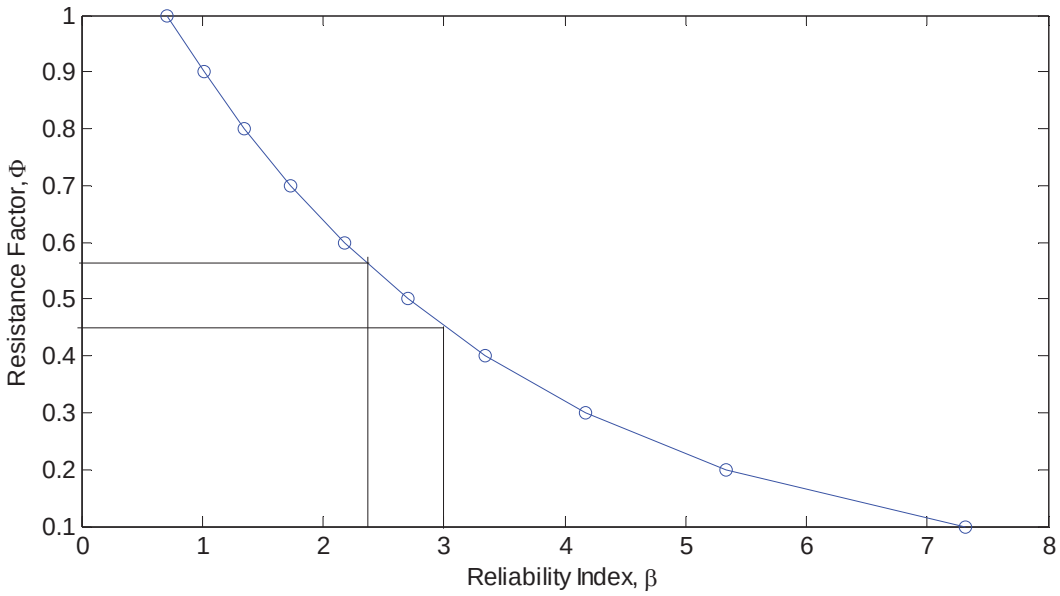


Figure F-M3-b Resistance factor calibration for 165cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Vietnam

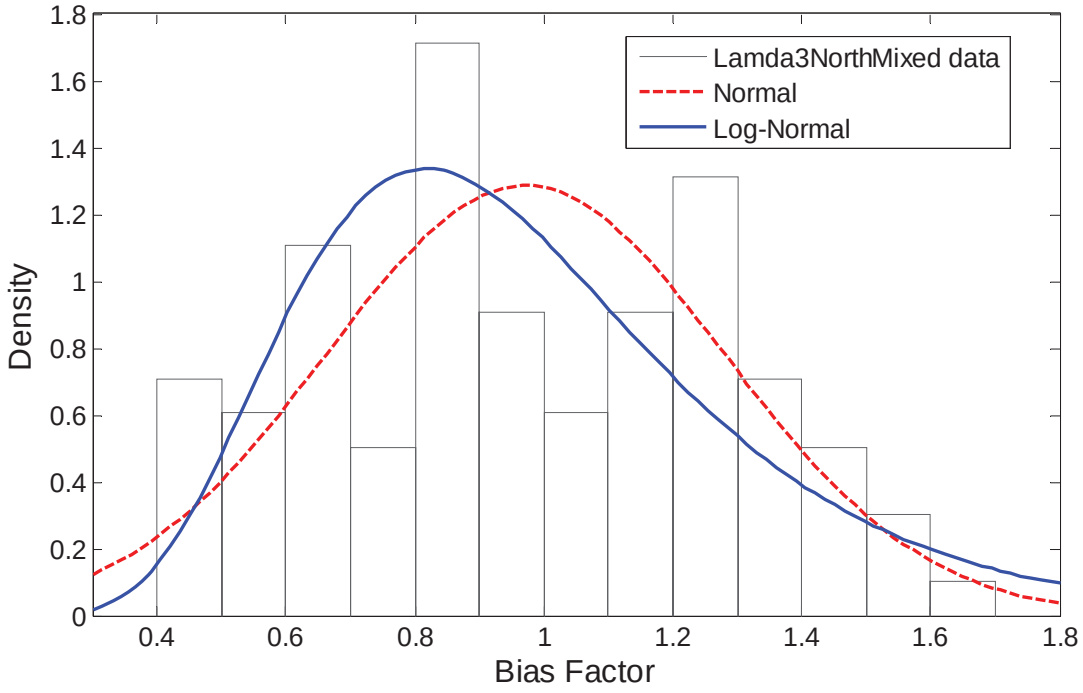


Figure F-M3-cHistogram and frequency distribution of bias factor λ3 for 99cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

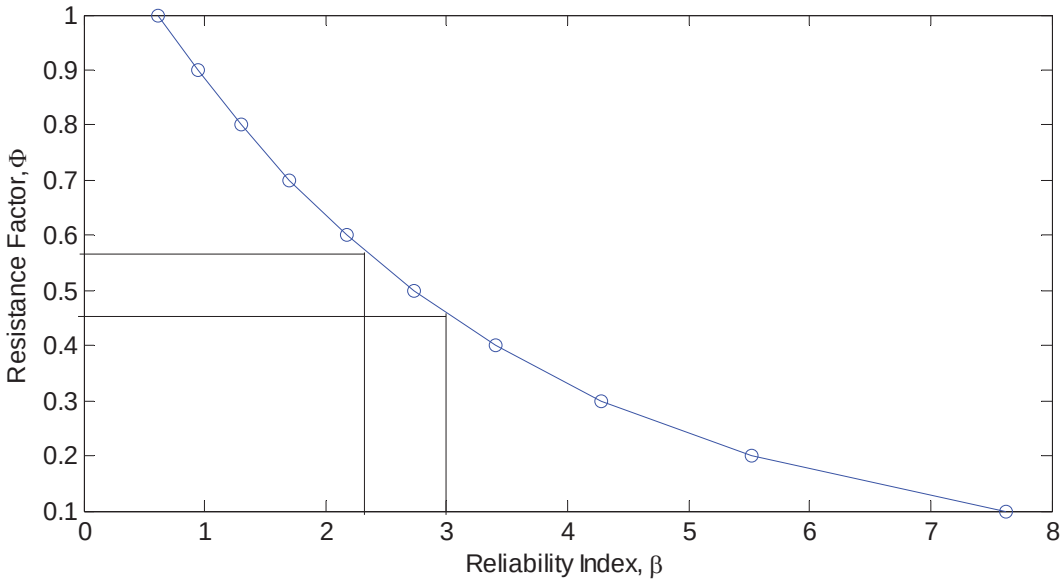


Figure F-M3-dResistance factor calibration for 99cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

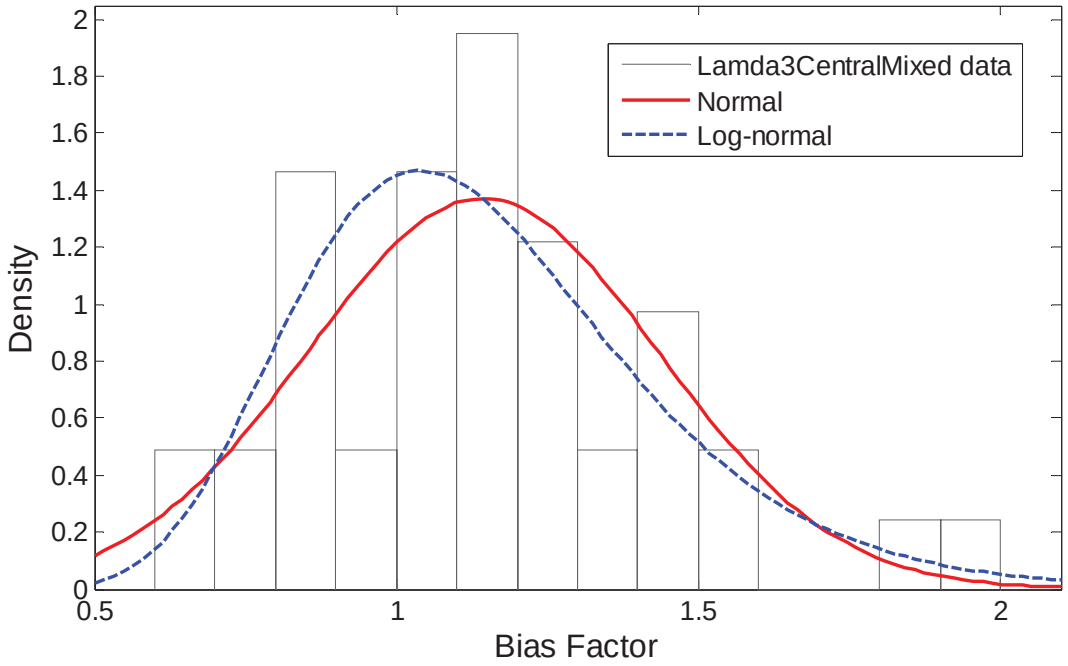


Figure F-M3-eHistogram and frequency distribution of bias factor λ3 for 41cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

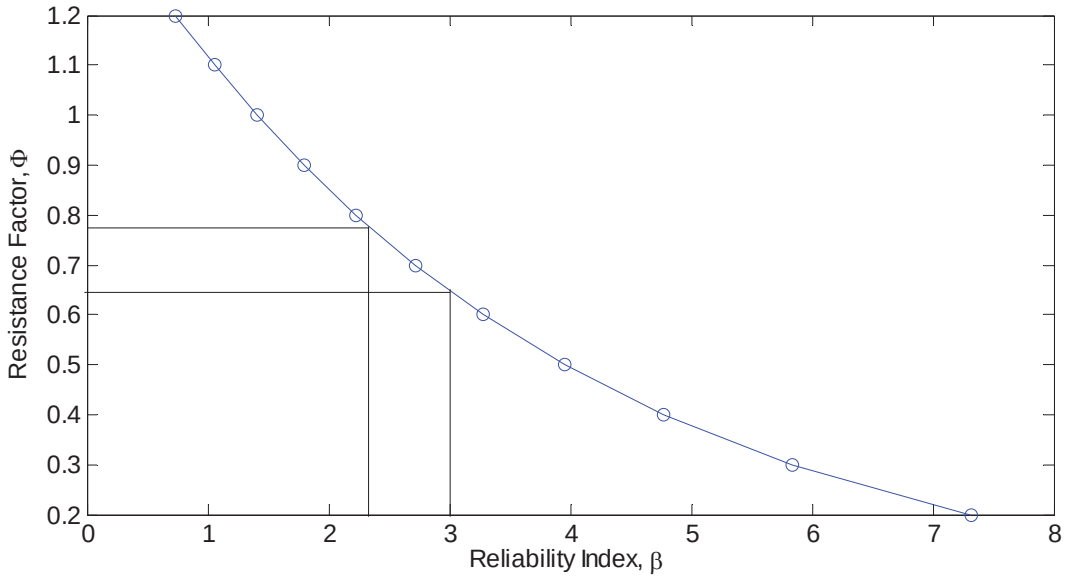


Figure F-M3-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

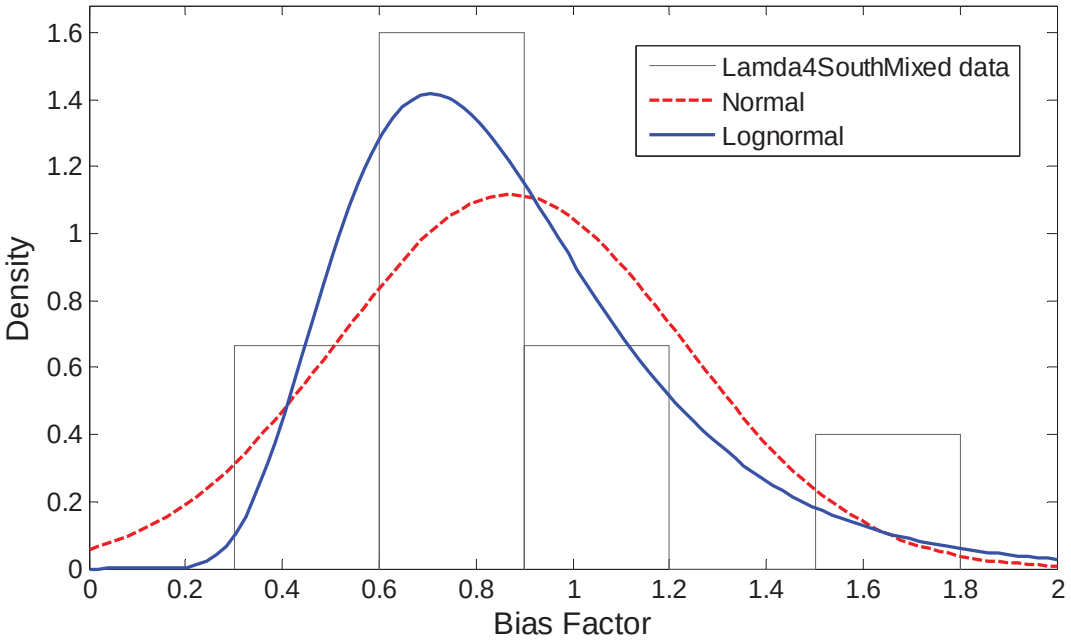


Figure F-M3-gHistogram and frequency distribution of bias factor λ3 for 25 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

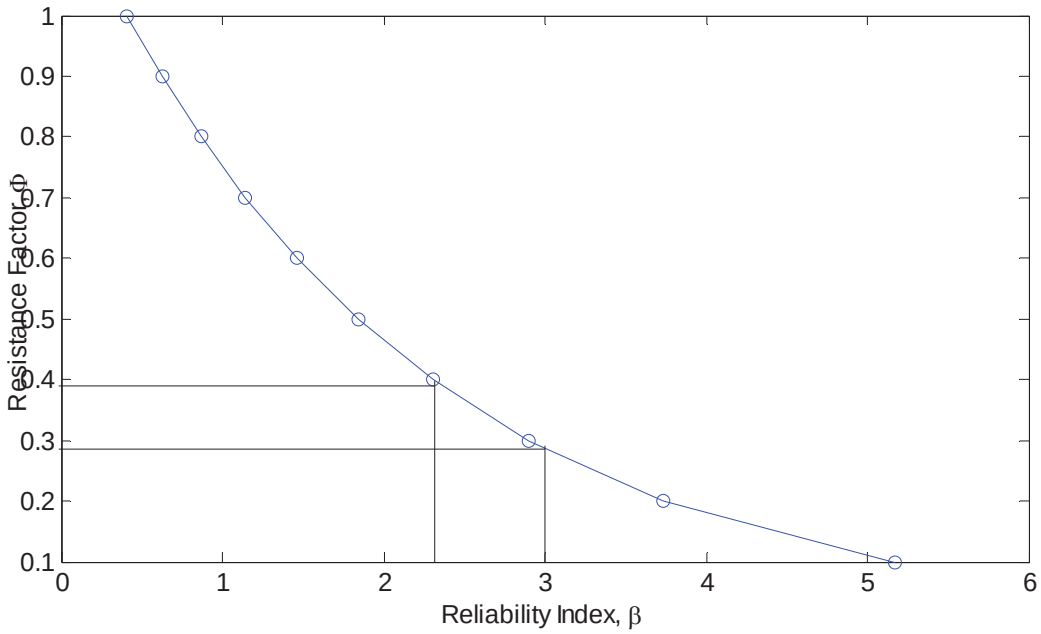


Figure F-M3-hResistance factor calibration for 25 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

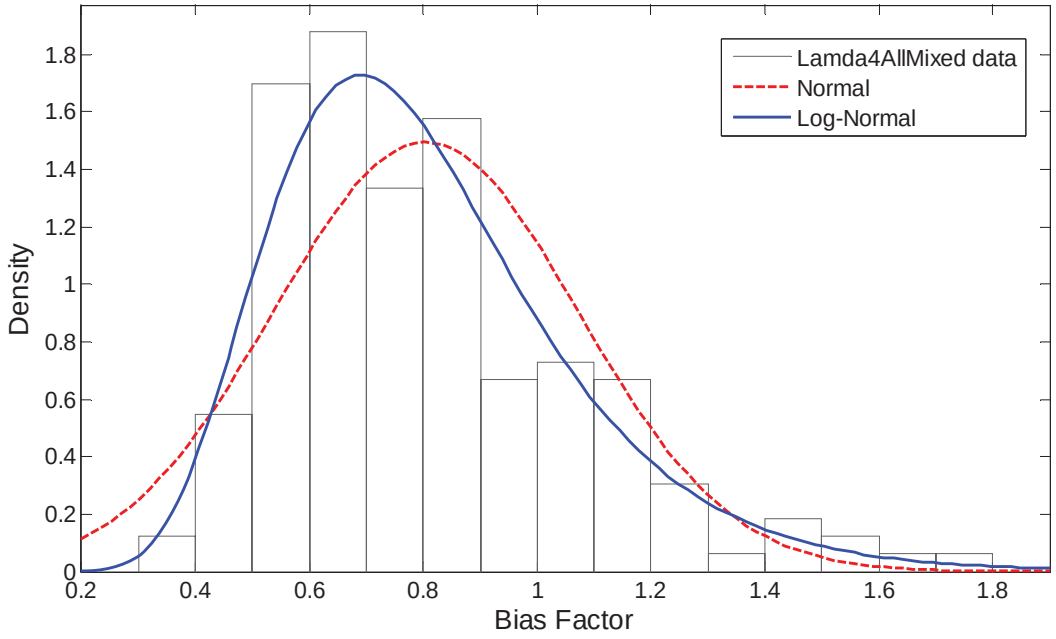


Figure F-M4-a Histogram and frequency distribution of bias factor λ4 for 165 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Vietnam

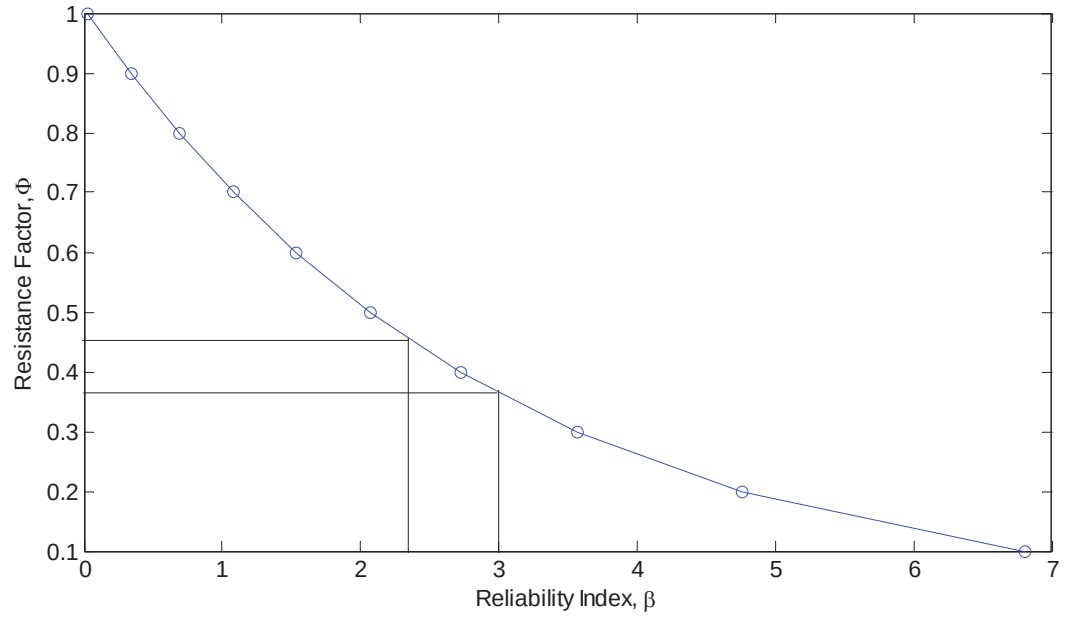


Figure F-M4-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Vietnam

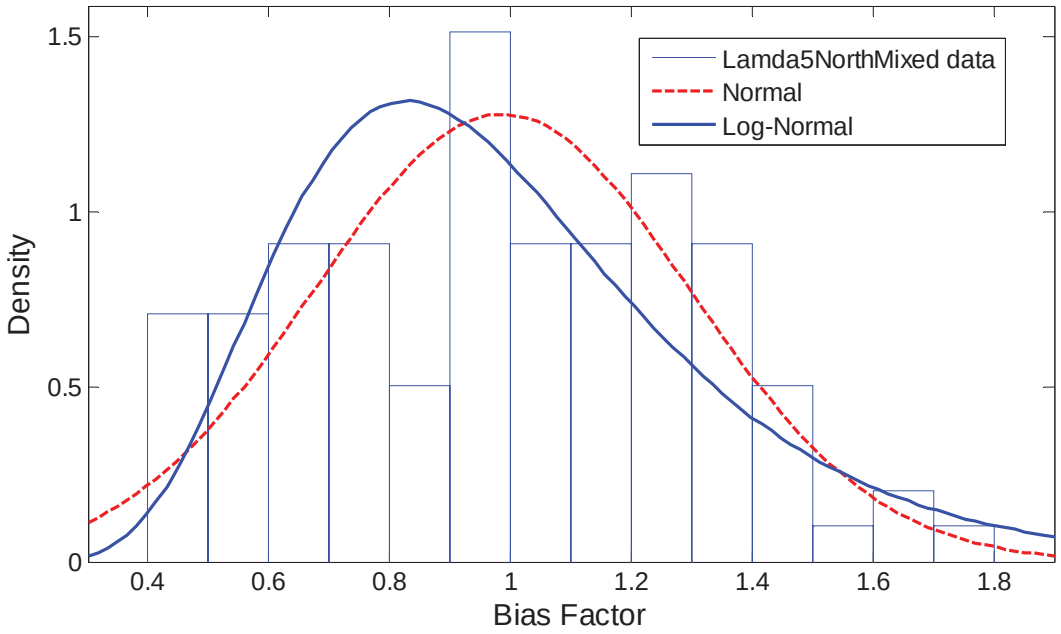


Figure F-M4-cHistogram and frequency distribution of bias factor λ4 for 99 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

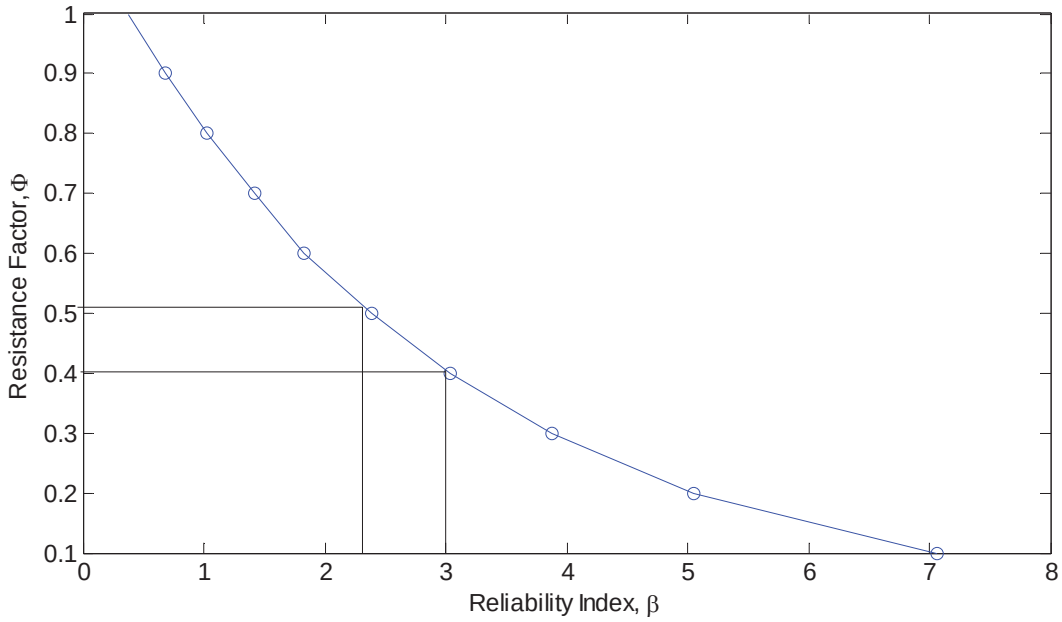


Figure F-M4-dResistance factor calibration for 99cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

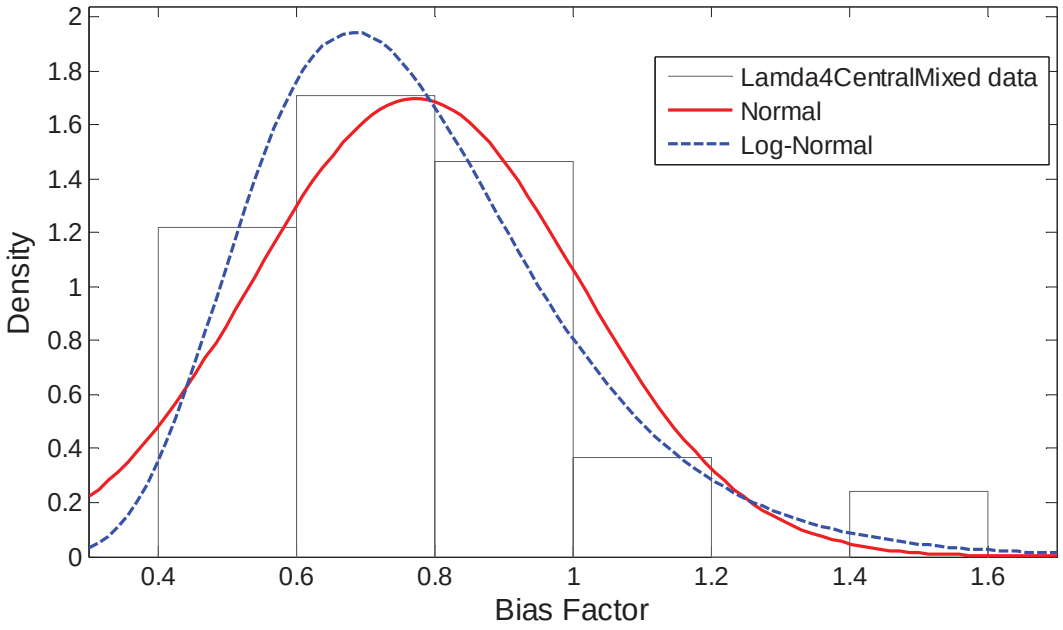


Figure F-M4-eHistogram and frequency distribution of bias factor λ4 for 41 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

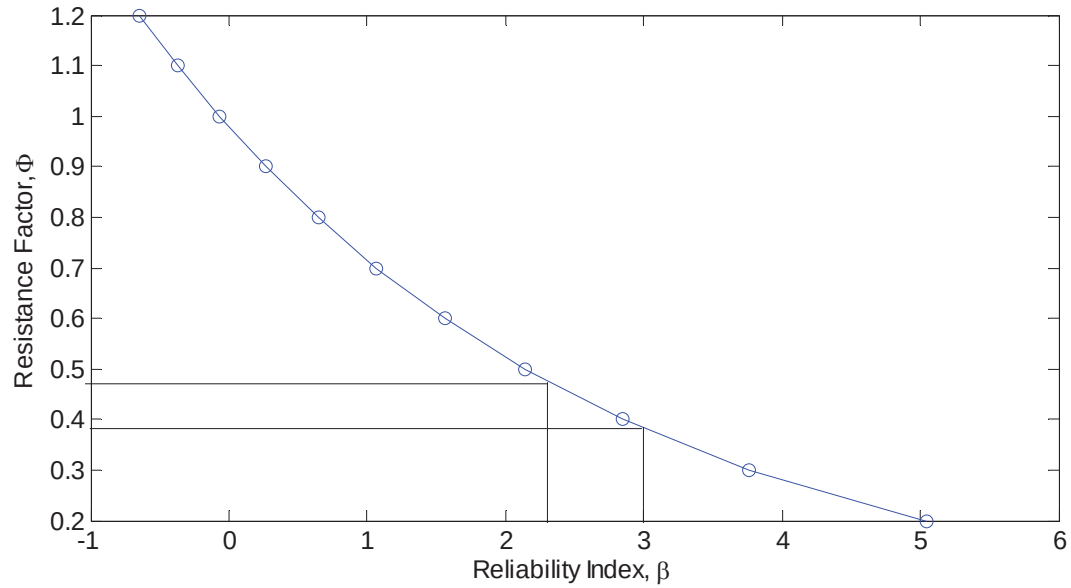


Figure F-M4-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

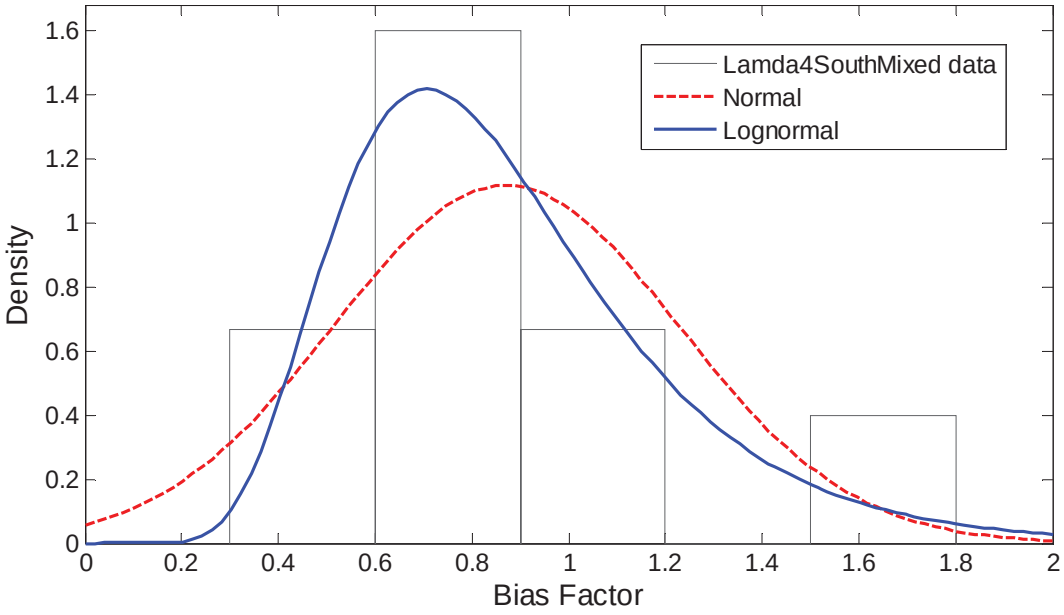


Figure F-M4-gHistogram and frequency distribution of bias factor λ4 for 25cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

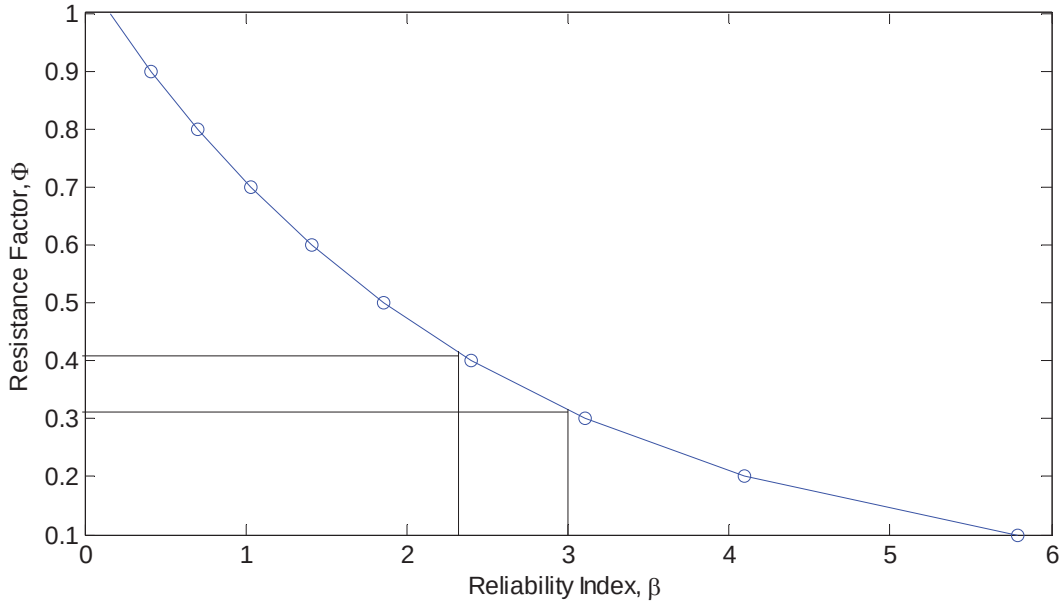


Figure F-M4-h Resistance factor calibration for 25 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

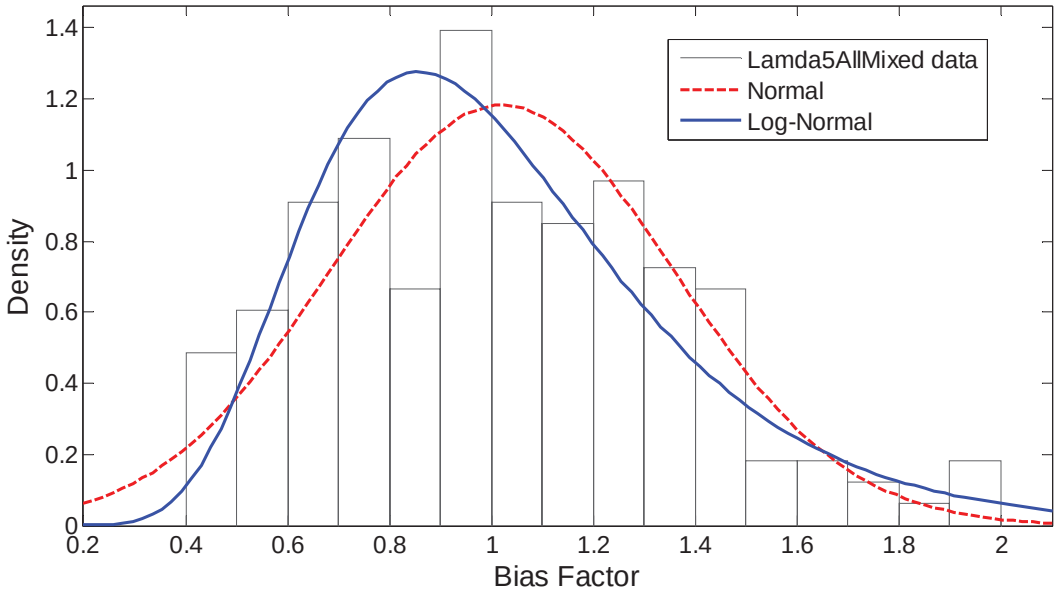
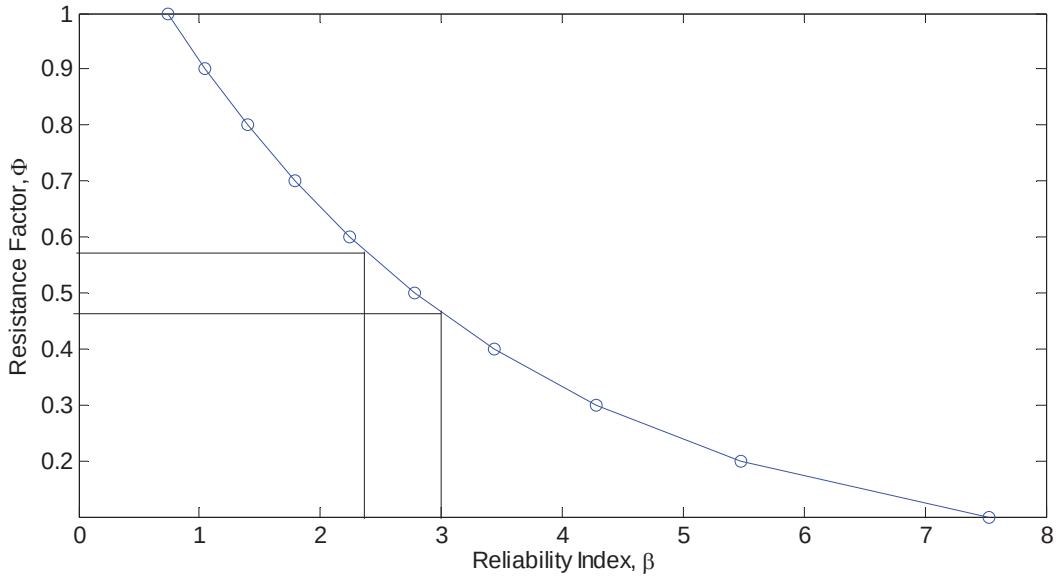
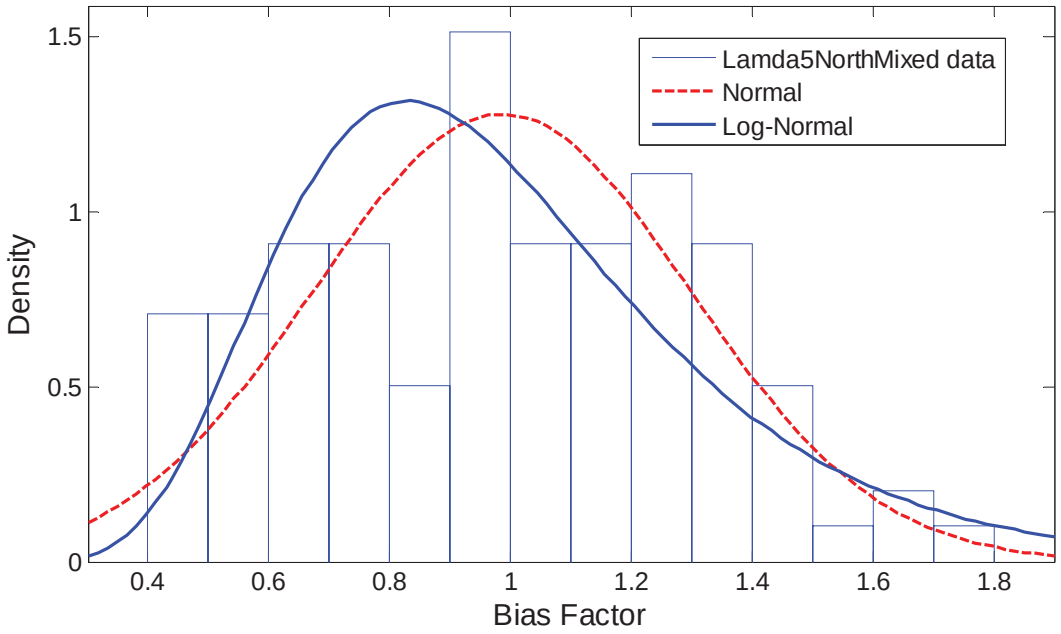


Figure F-M5-a Histogram and frequency distribution of bias factor λ5 for 165cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Vietnam



FigureF-M5-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Vietnam



FigureF-M5-c Histogram and frequency distribution of bias factor λ5 for 99 cases of concrete piles in Mixed soils using the λ and Nordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

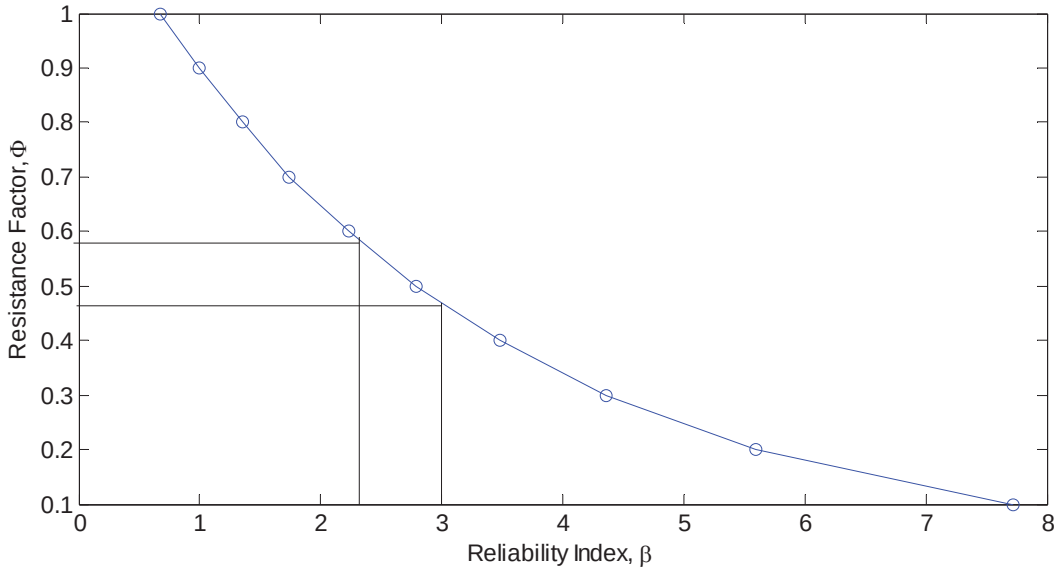


Figure F-M5-d Resistance factor calibration for 99 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

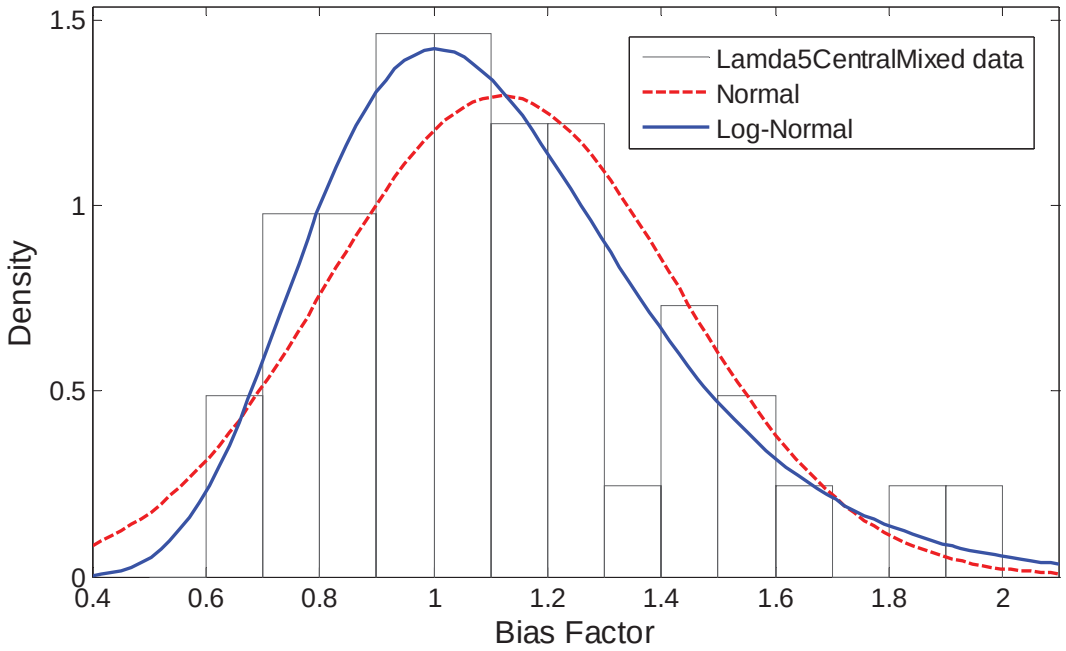


Figure F-M5-eHistogram and frequency distribution of bias factor λ5 for 41 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

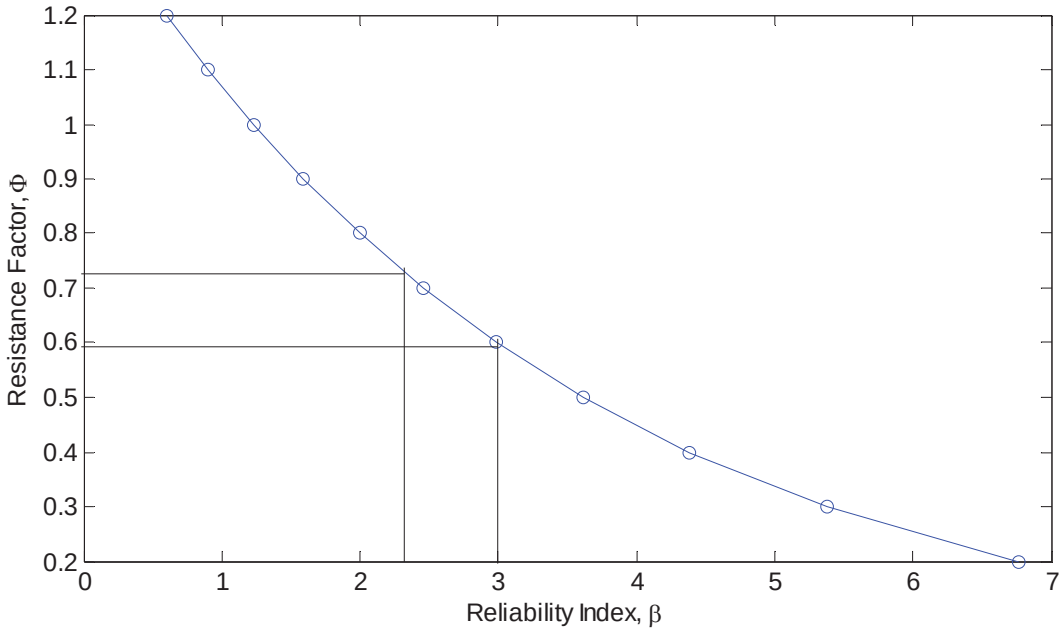


Figure F-M5-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

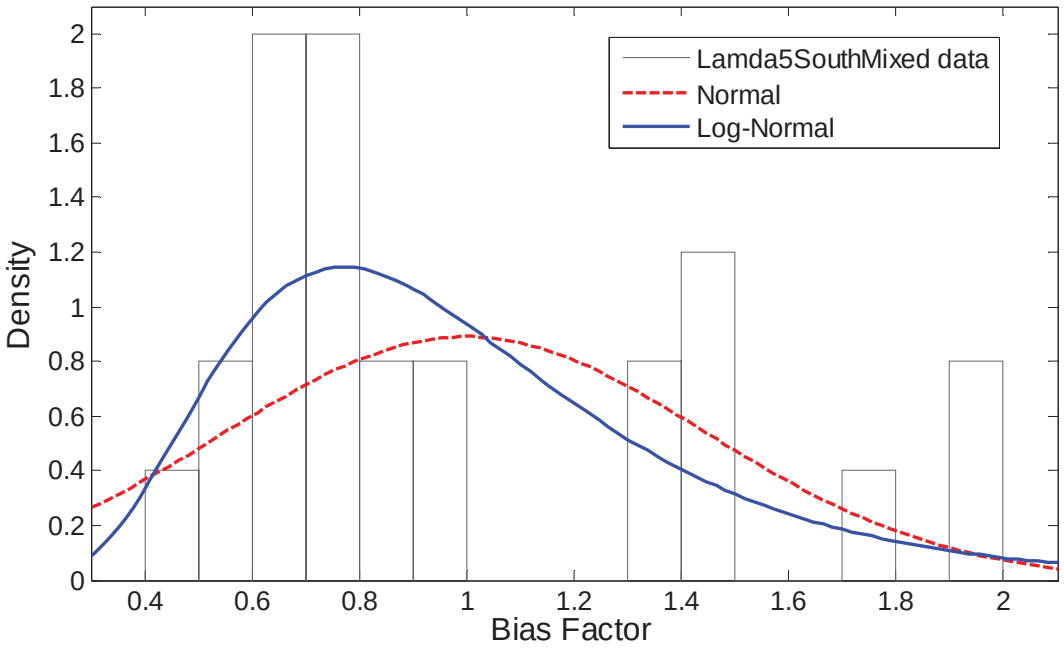


Figure F-M5-gHistogram and frequency distribution of bias factor λ5 for 25 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

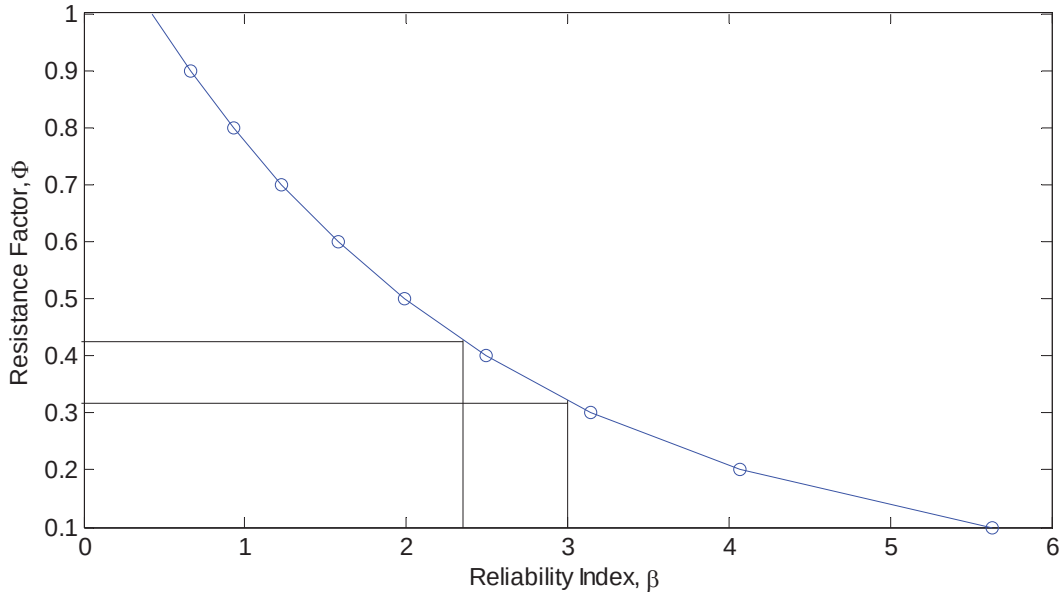


Figure F-M5-hResistance factor calibration for 25 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

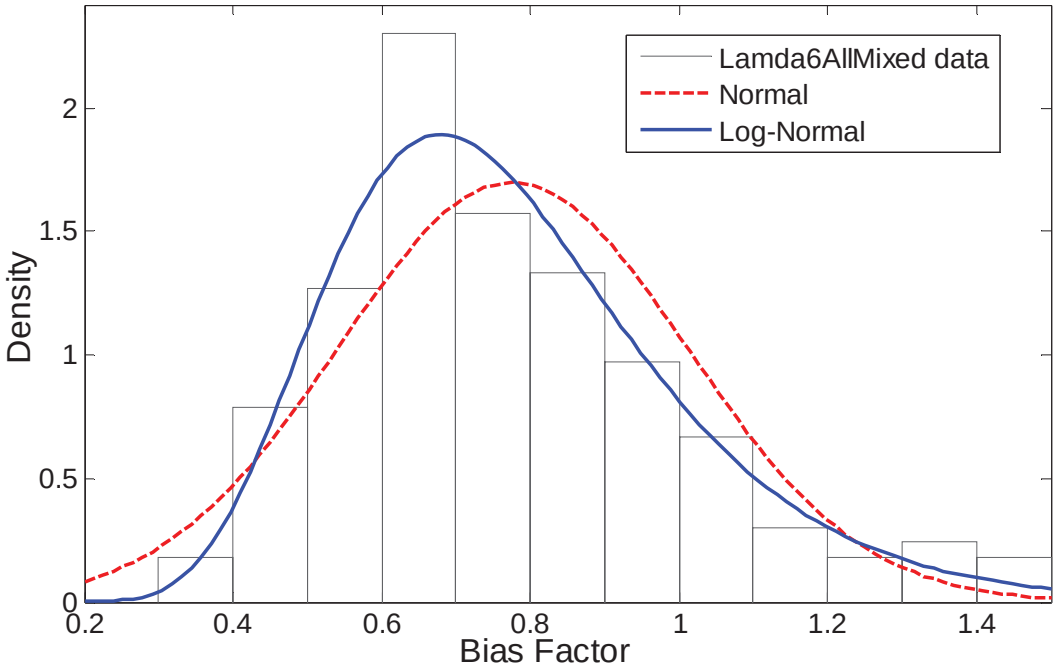


Figure F-M6-aHistogram and frequency distribution of bias factor λ6 for 165 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Vietnam

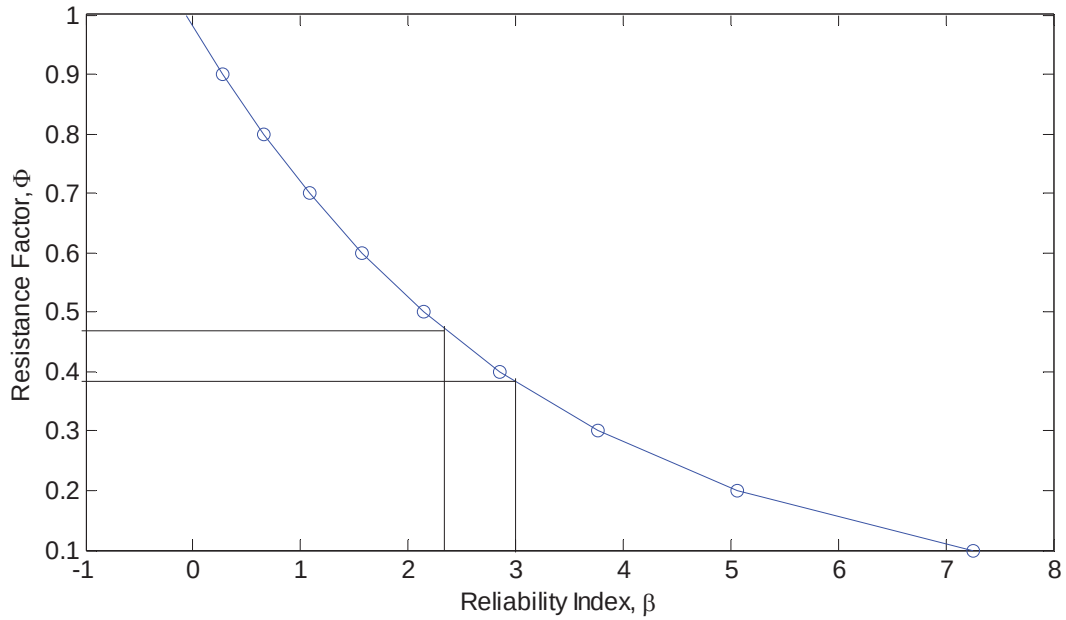


Figure F-M6-bResistance factor calibration for 165cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Vietnam

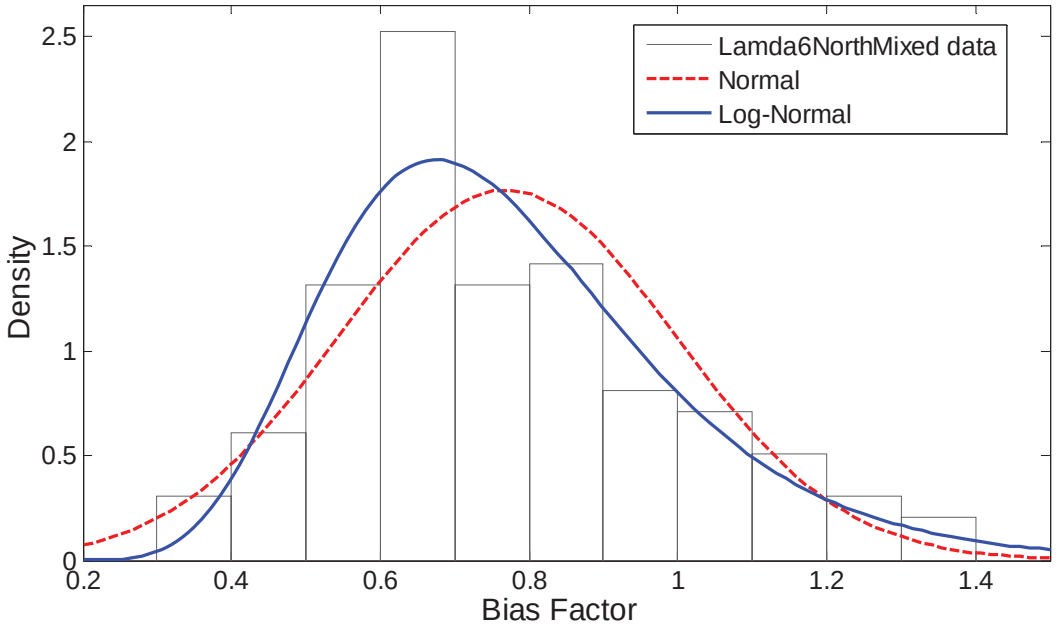


Figure F-M6-cHistogram and frequency distribution of bias factor λ6 for 99 cases of concrete piles in Mixed soils using the λ and Nordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

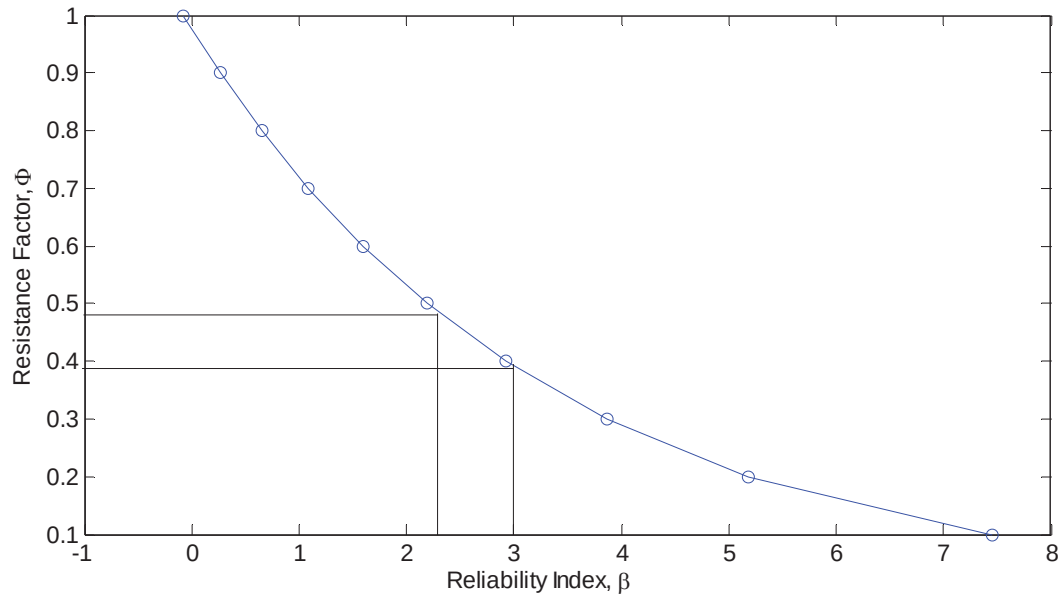


Figure F-M6-dResistance factor calibration for 99 cases of concrete piles in Mixed soils using the λ and Nordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in North of Vietnam

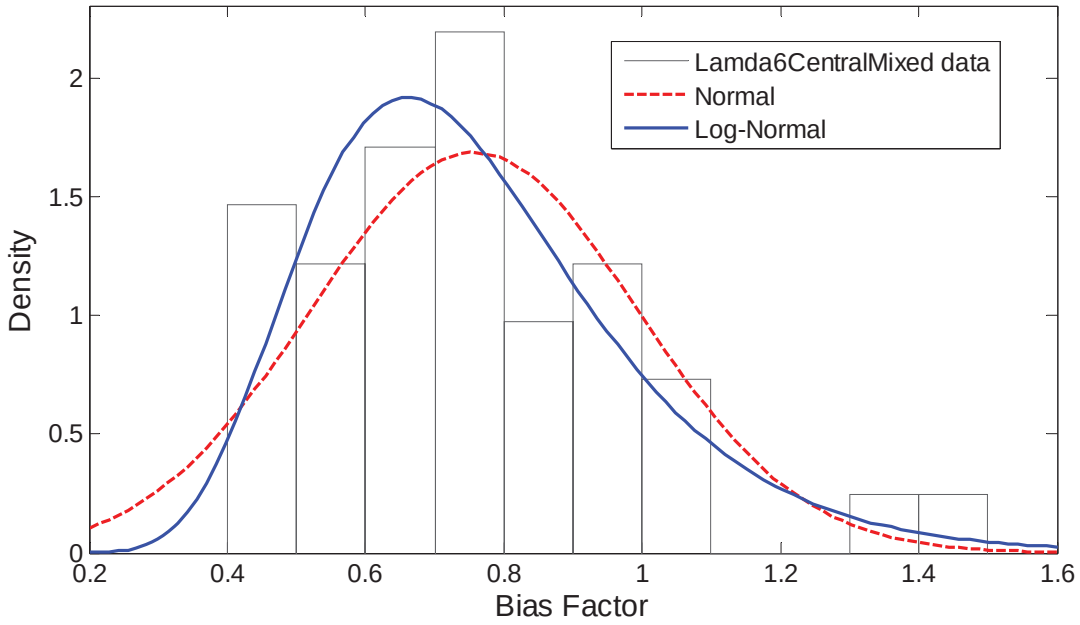


Figure F-M6-eHistogram and frequency distribution of bias factor λ6 for 41 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

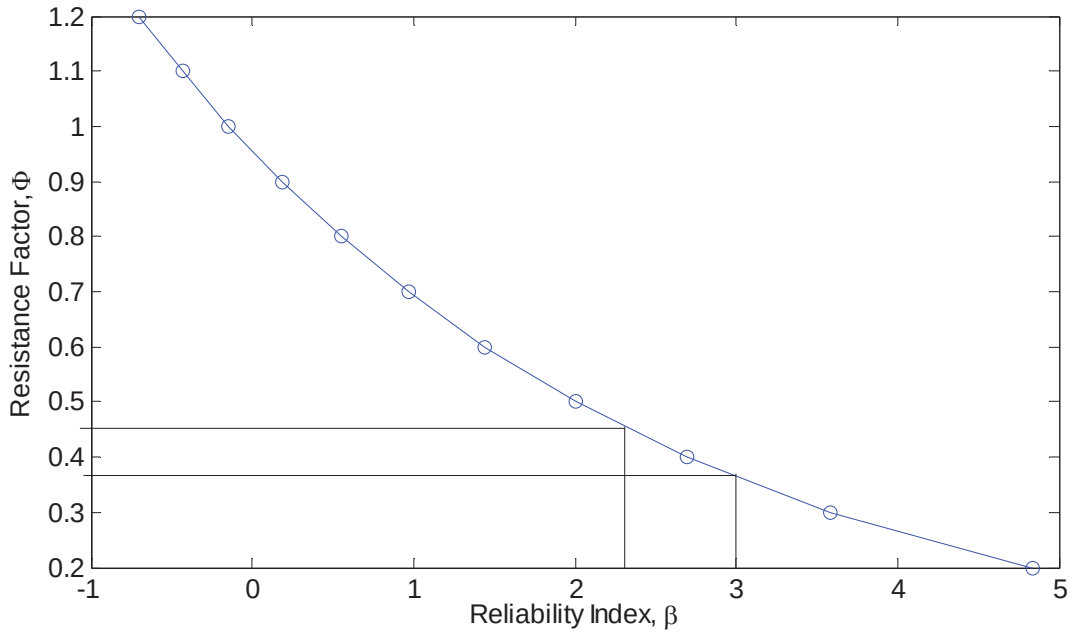


Figure F-M6-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

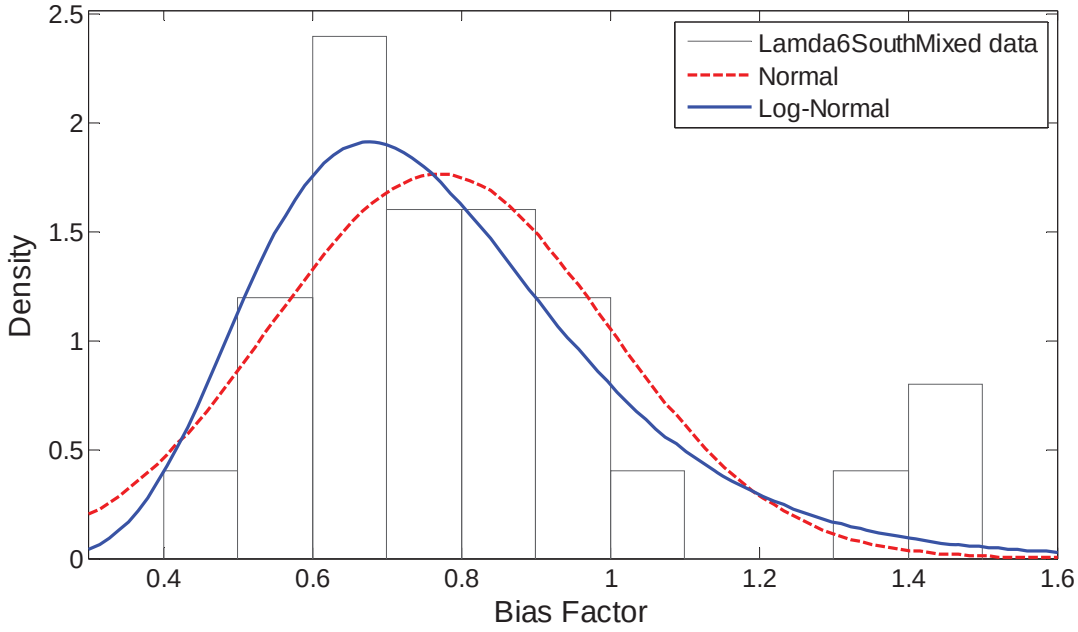


Figure F-M6-gHistogram and frequency distribution of bias factor λ6 for 25 cases of concrete piles in Mixed soils using the λ and Nordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

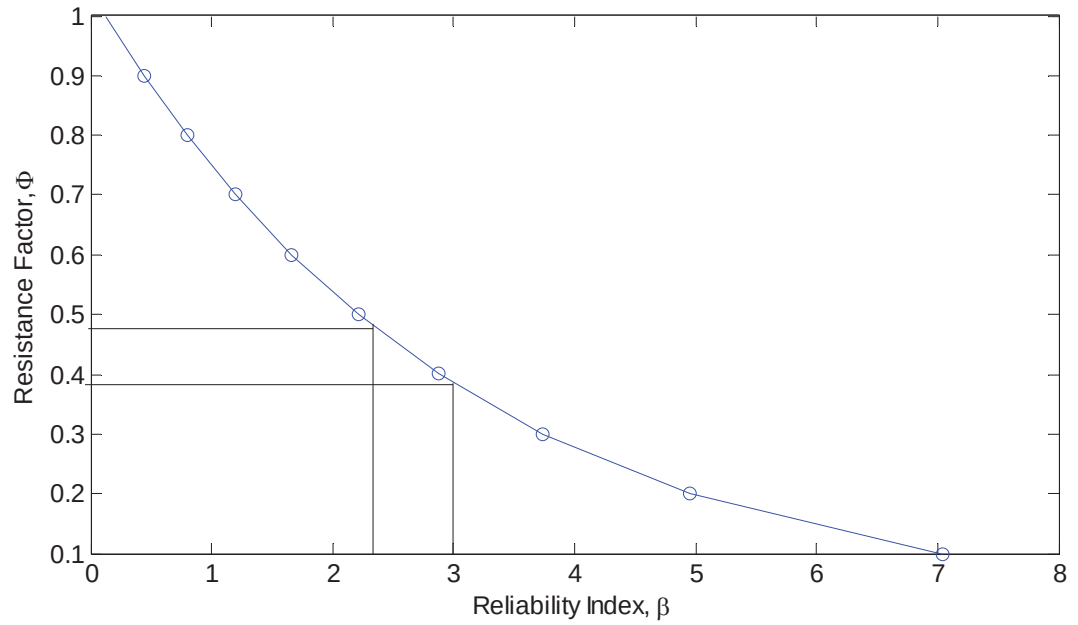


Figure F-M6-h Resistance factor calibration for 25 cases of concrete piles in Mixed soils using the λ and Nordlund/Thurman method (Su: Hara, ϕ: Peck, Hanson and Thornburn) in South of Vietnam

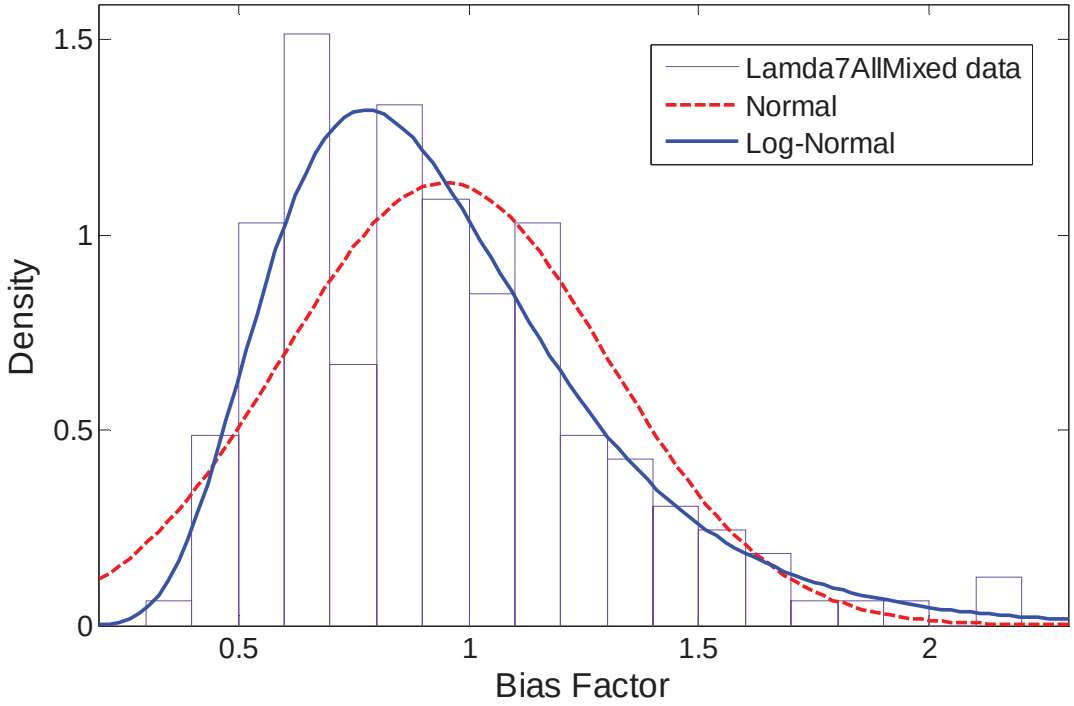


Figure F-M7-aHistogram and frequency distribution of bias factor λ7 for 165 cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ: Peck, Hanson and Thornburn) in Vietnam

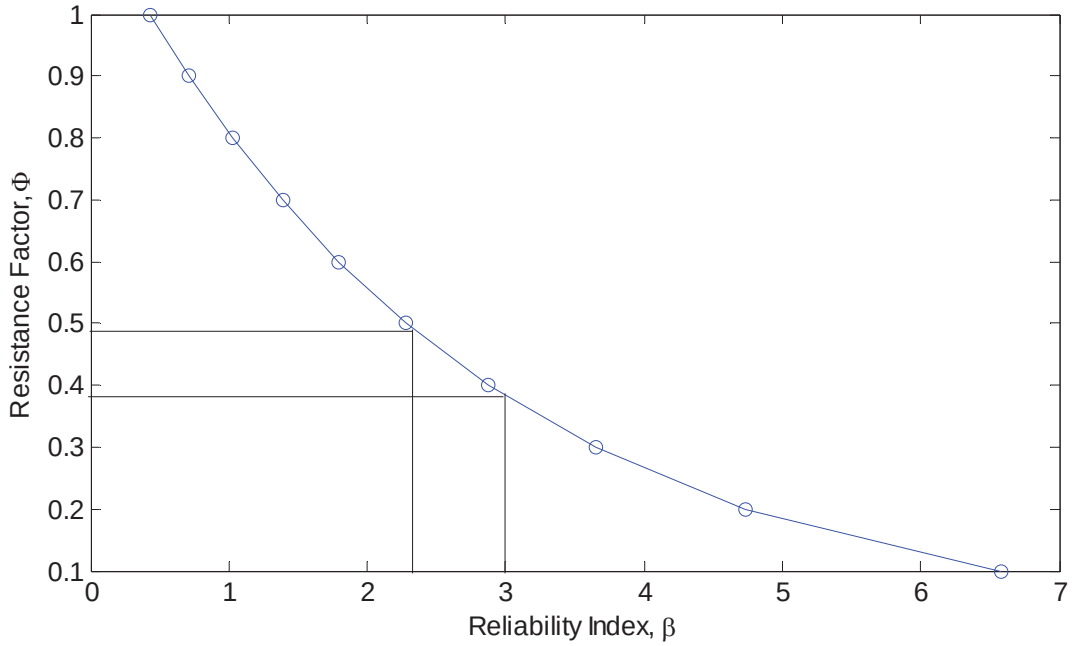


Figure F-M7-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ: Peck, Hanson and Thornburn) in Vietnam

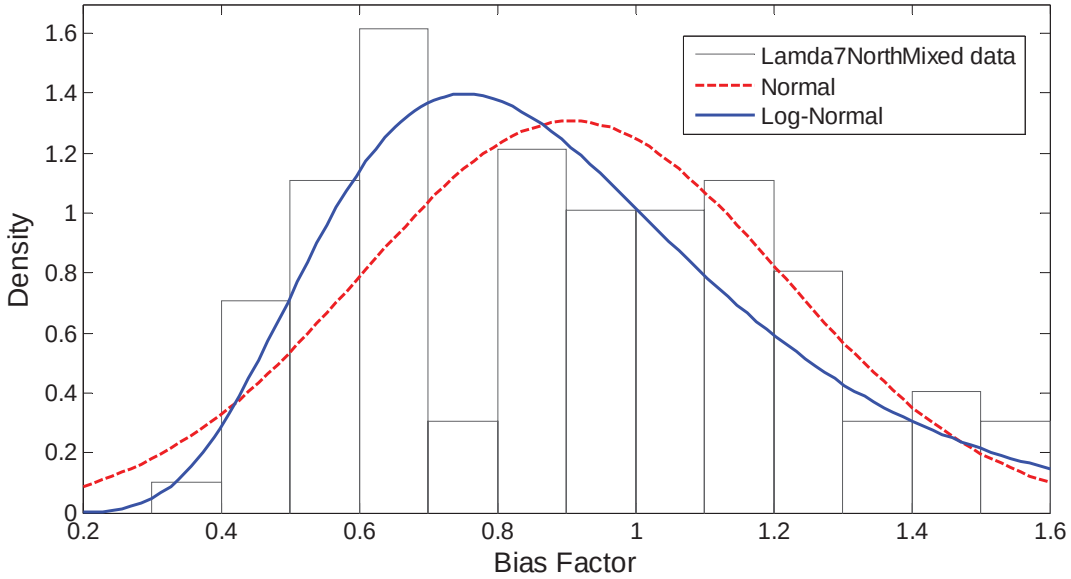


Figure F-M7-cHistogram and frequency distribution of bias factor λ7 for 99 cases of concrete piles in Mixed soils using the βBurland and Nordlund/Thurman method (ϕ: Peck, Hanson and Thornburn) in North of Vietnam

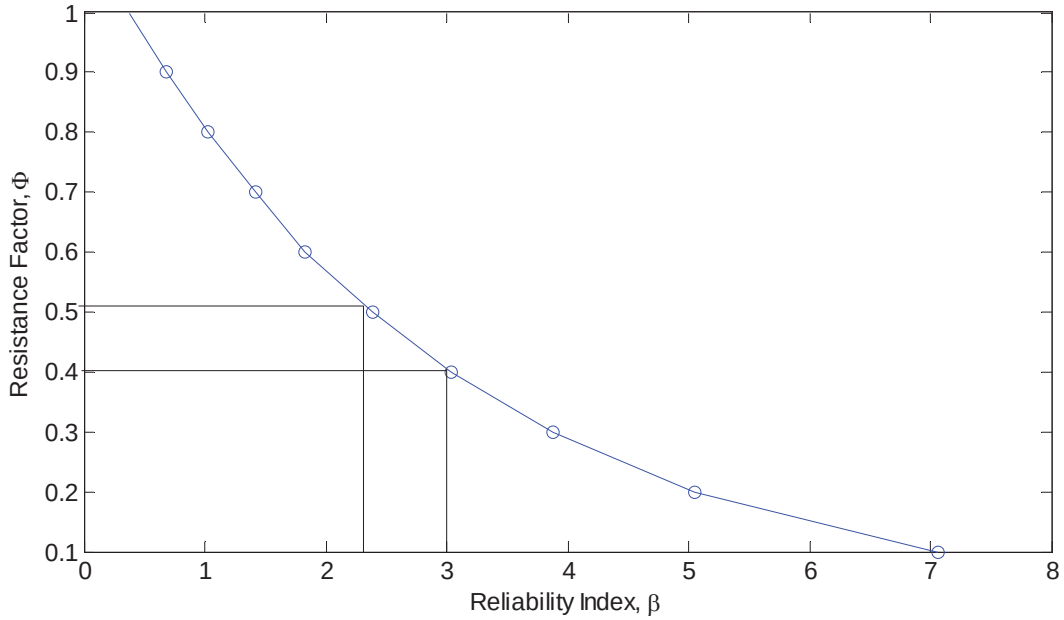


Figure F-M7-dResistance factor calibration for 99 cases of concrete piles in Mixed soils using the βBurland and Nordlund/Thurman method (ϕ: Peck, Hanson and Thornburn) in North of Vietnam

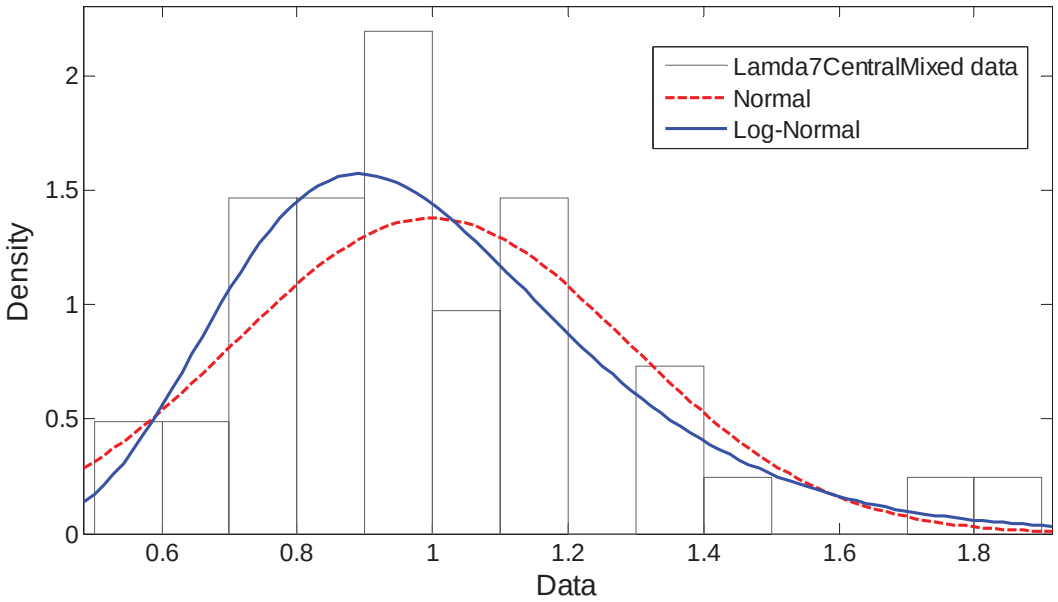


Figure F-M7-eHistogram and frequency distribution of bias factor λ7 for 41cases of concrete piles in Mixed soils using the β Burland and Nordlund/Thurman method (ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

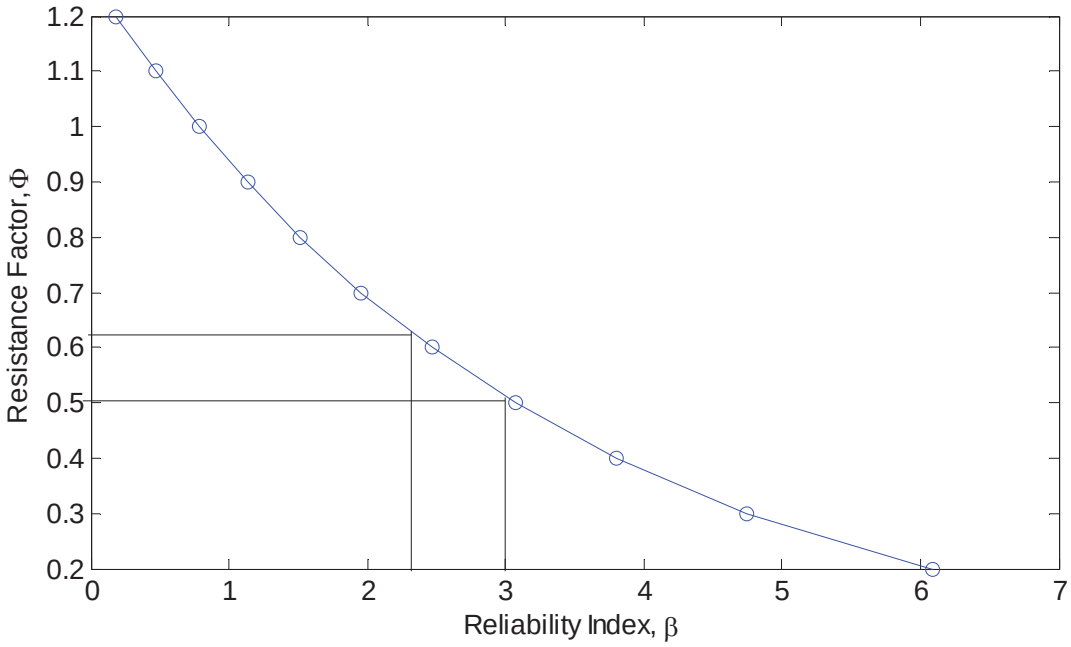


Figure F-M7-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ: Peck, Hanson and Thornburn) in Central of Vietnam

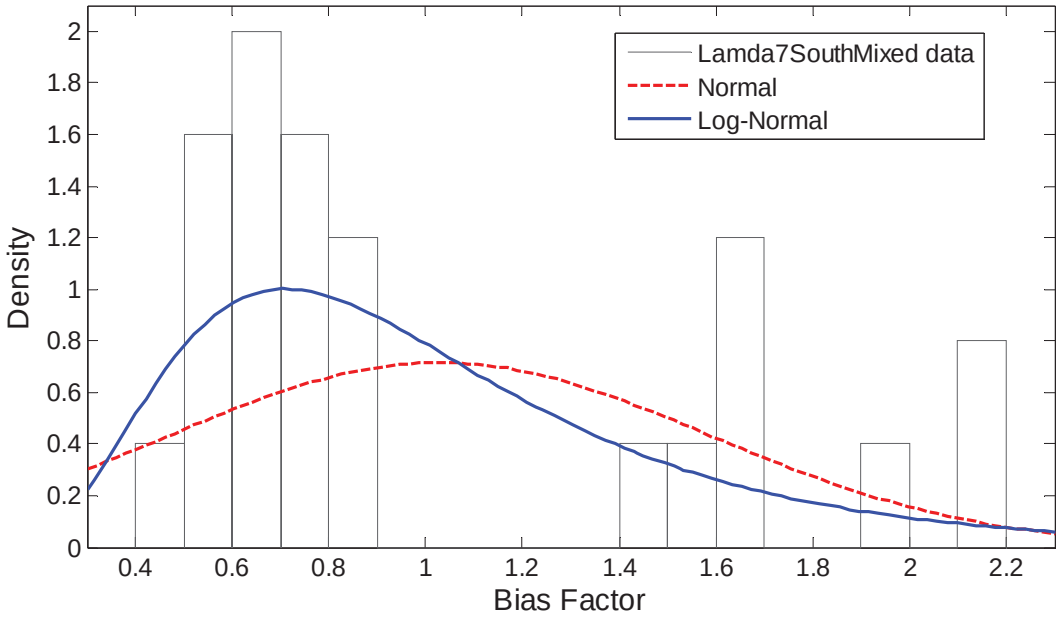


Figure F-M7-gHistogram and frequency distribution of bias factor λ7 for 25cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ: Peck, Hanson and Thornburn) in South of Vietnam

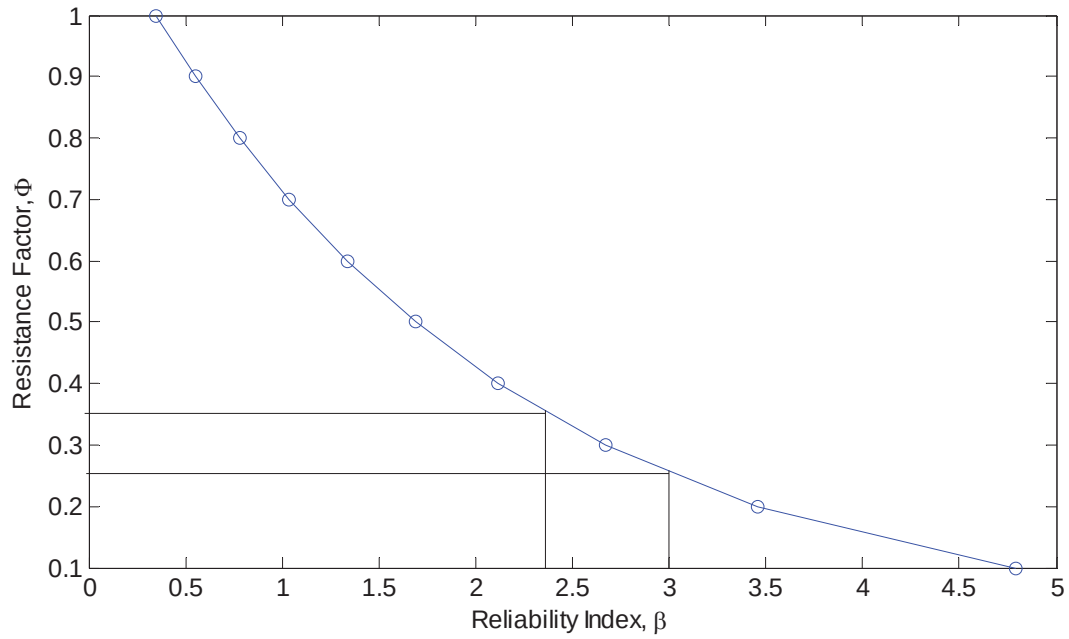


Figure F-M7-hResistance factor calibration for 25 cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ: Peck, Hanson and Thornburn) in South of Vietnam

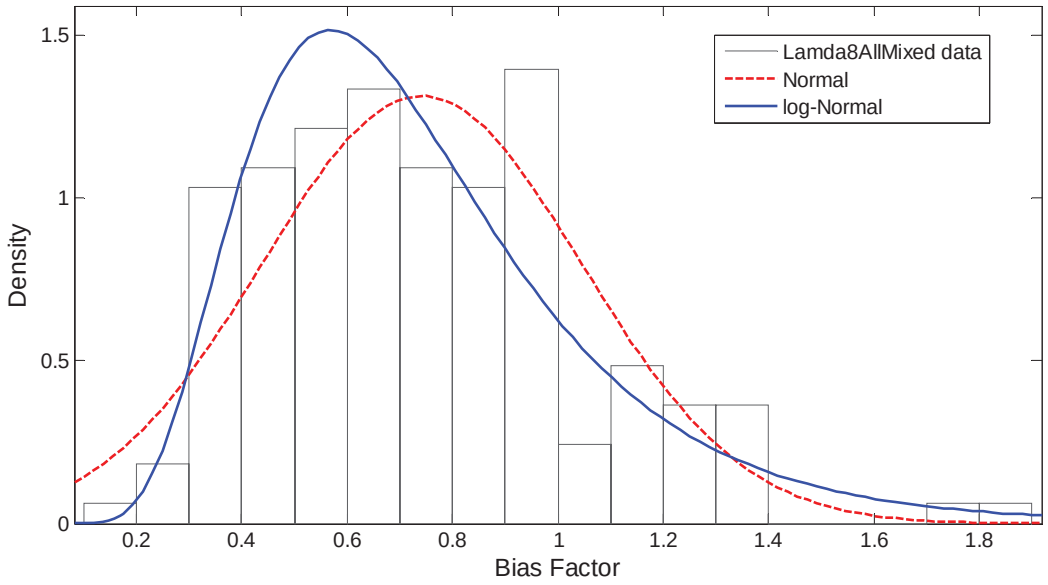


Figure F-M8-aHistogram and frequency distribution of bias factor λ8 for 165 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Vietnam

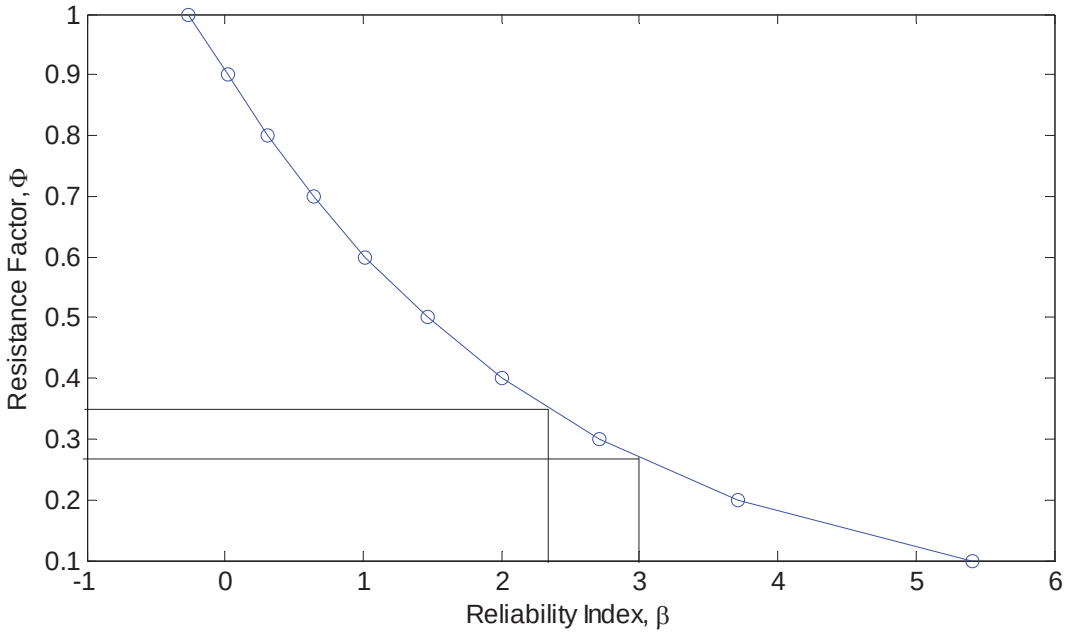


Figure F-M8-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Vietnam

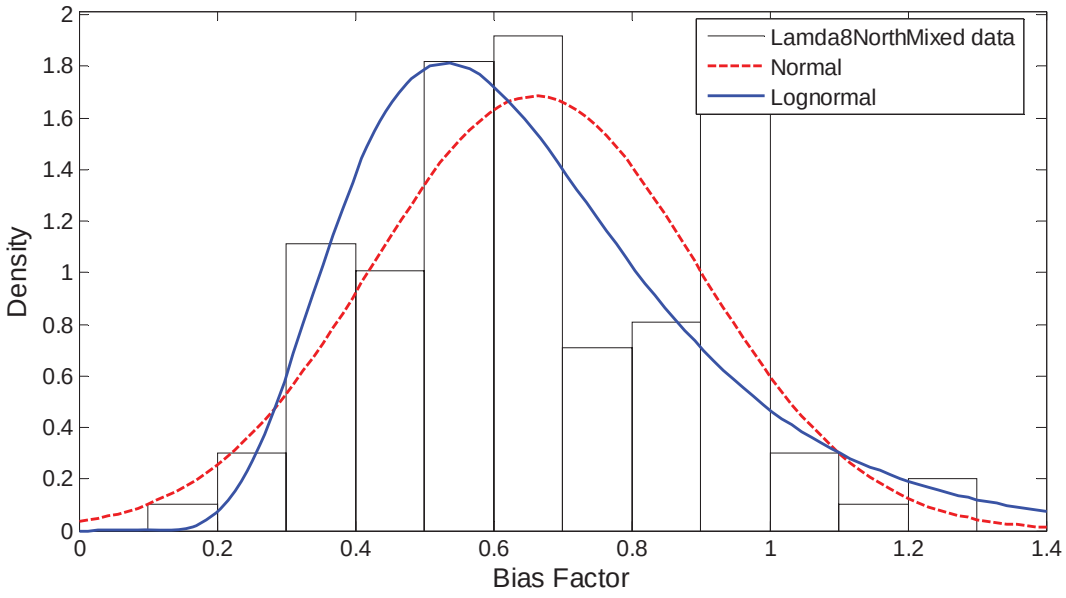


Figure F-M8-cHistogram and frequency distribution of bias factor λ8 for 99 cases of concrete piles in Mixed soils using the α-Tomlinson and Nordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in North of Vietnam

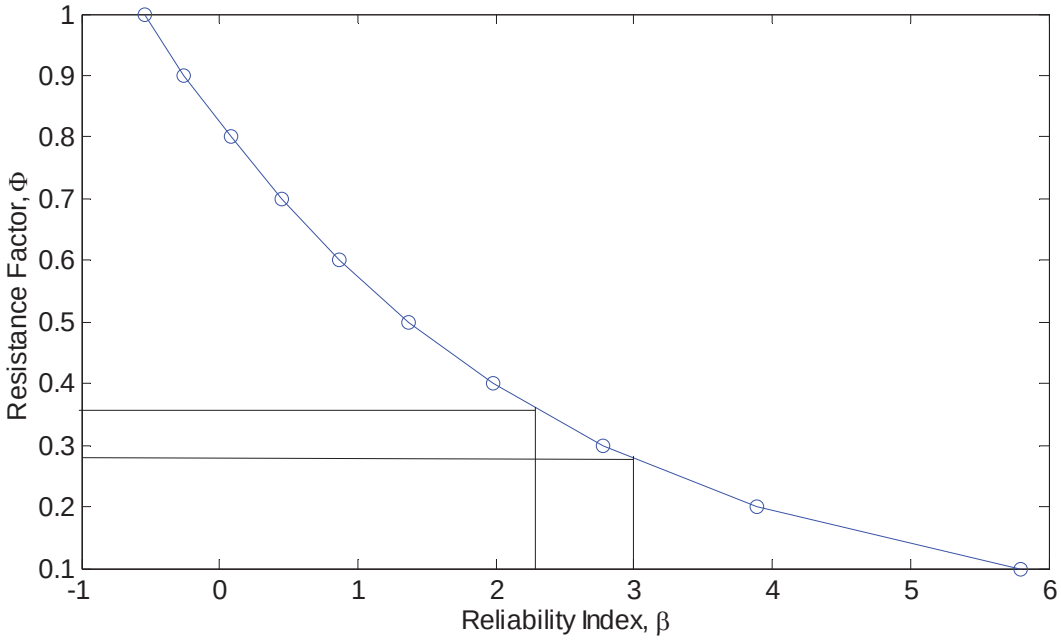


Figure F-M8-dResistance factor calibration for 99 cases of concrete piles in Mixed soils using the α-Tomlinson and Nordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in North of Vietnam

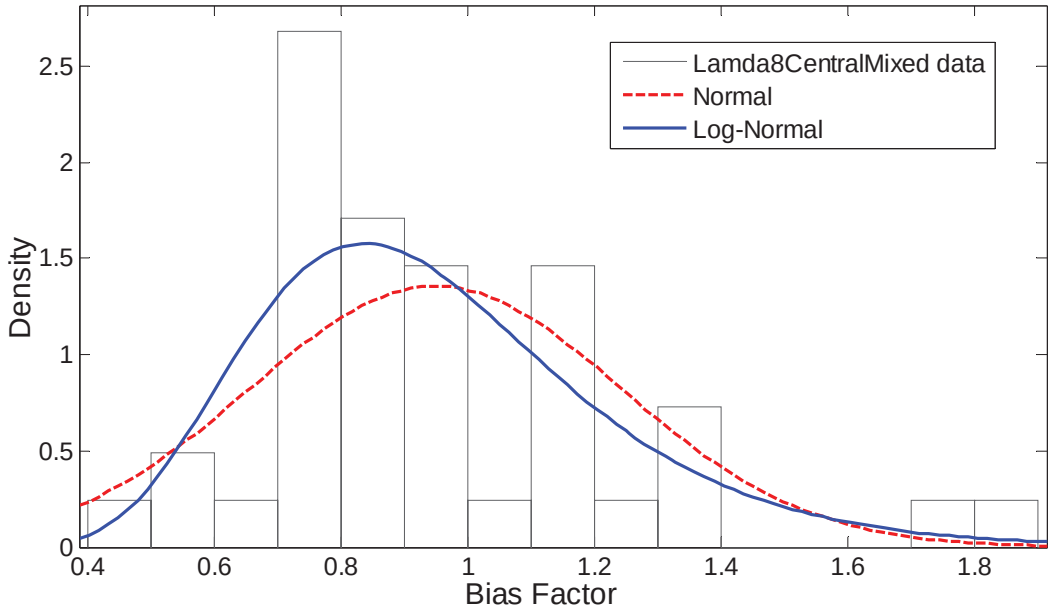


Figure F-M8-eHistogram and frequency distribution of bias factor λ8 for 41cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Central of Vietnam

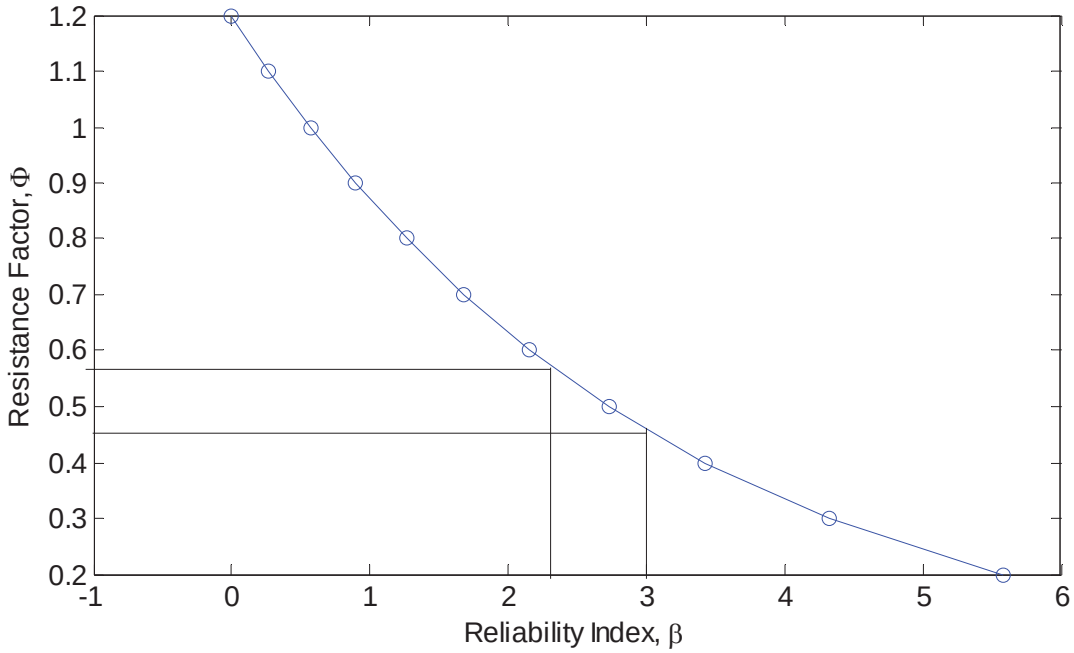


Figure F-M8-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Central of Vietnam

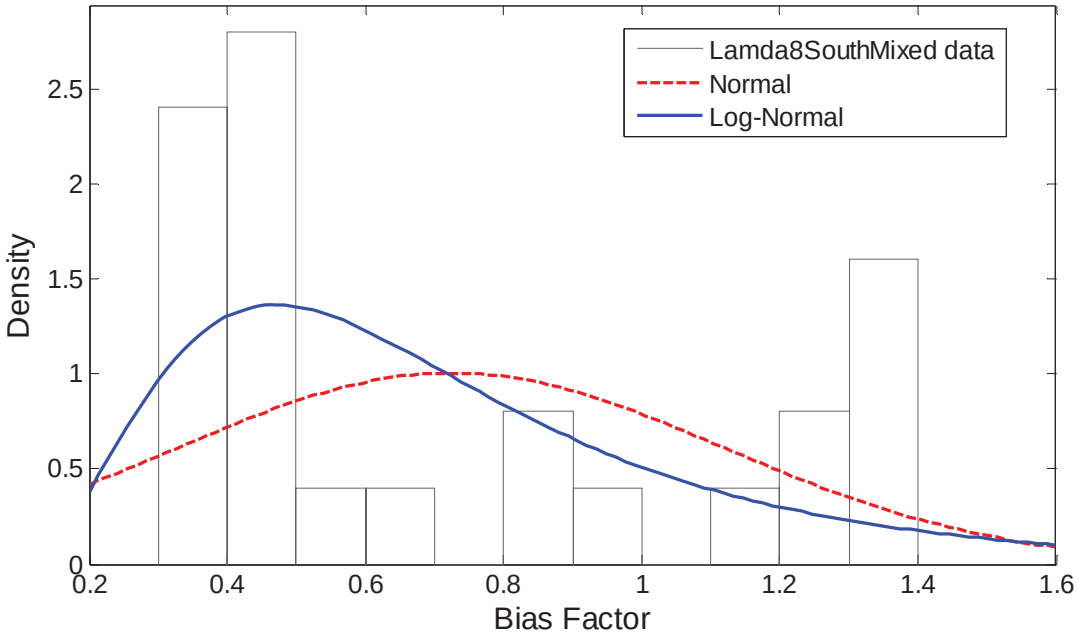


Figure F-M8-gHistogram and frequency distribution of bias factor λ8 for 25 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in South of Vietnam

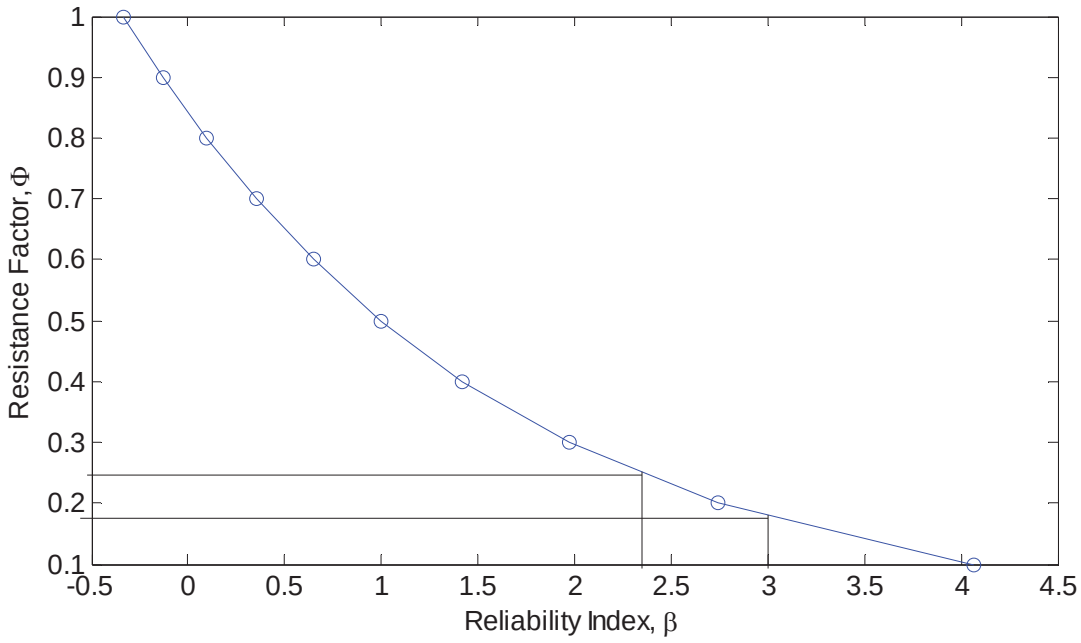


Figure F-M8-hResistance factor calibration for 25 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in South of Vietnam

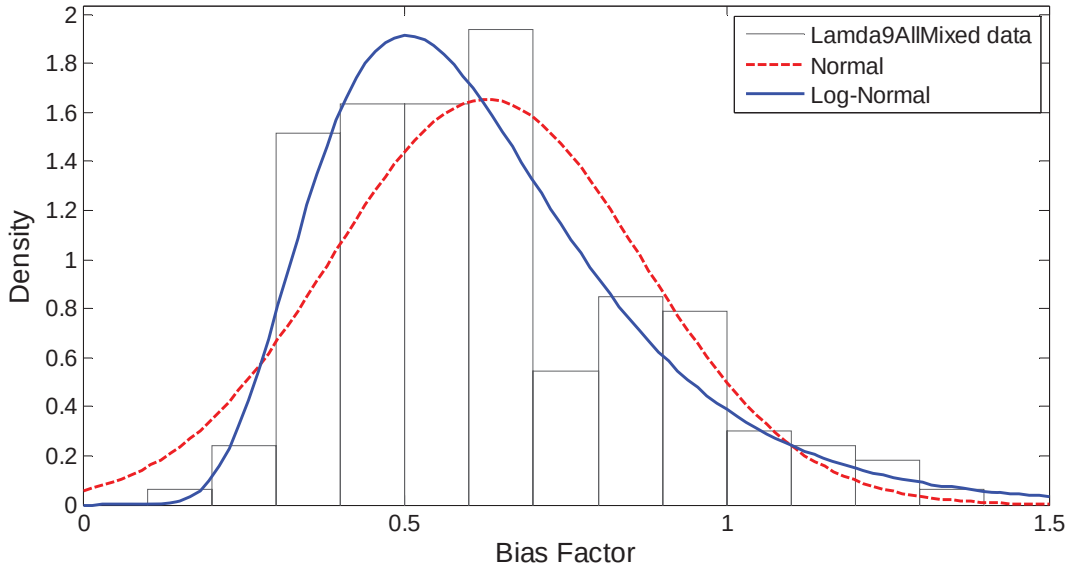


Figure F-M9-aHistogram and frequency distribution of bias factor λ9 for 165 cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ:Schmertmann) in Vietnam

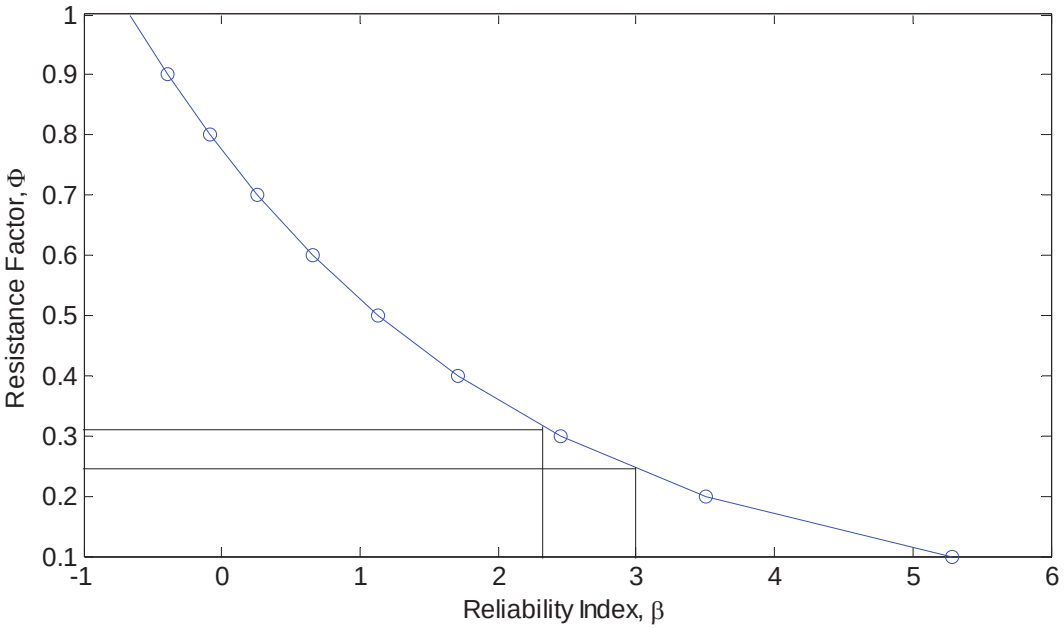


Figure F-M9-bResistance factor calibration for 165cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ:Schmertmann) in Vietnam

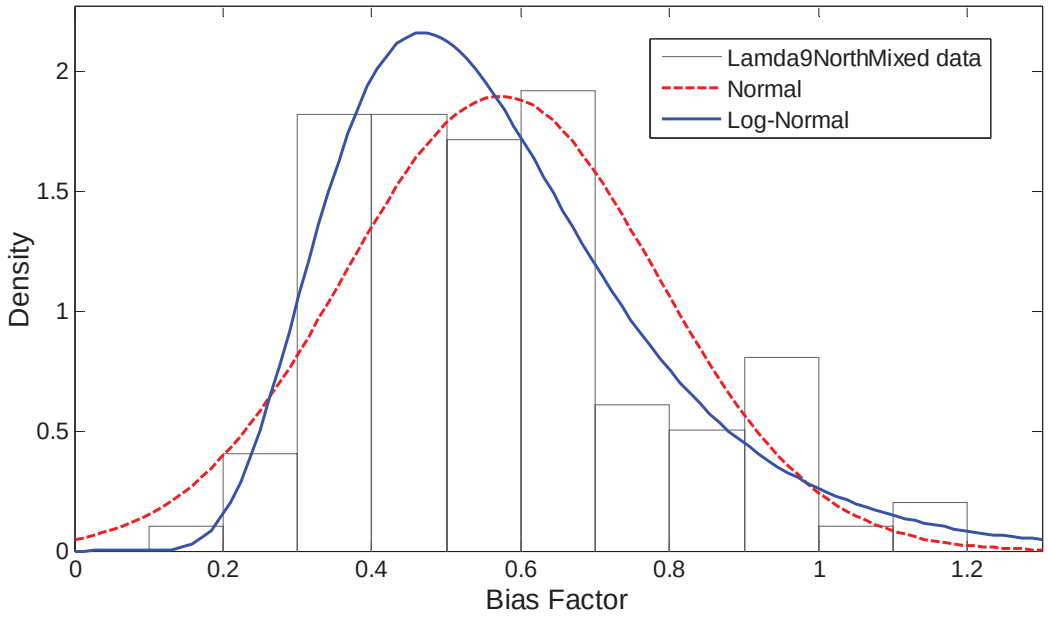
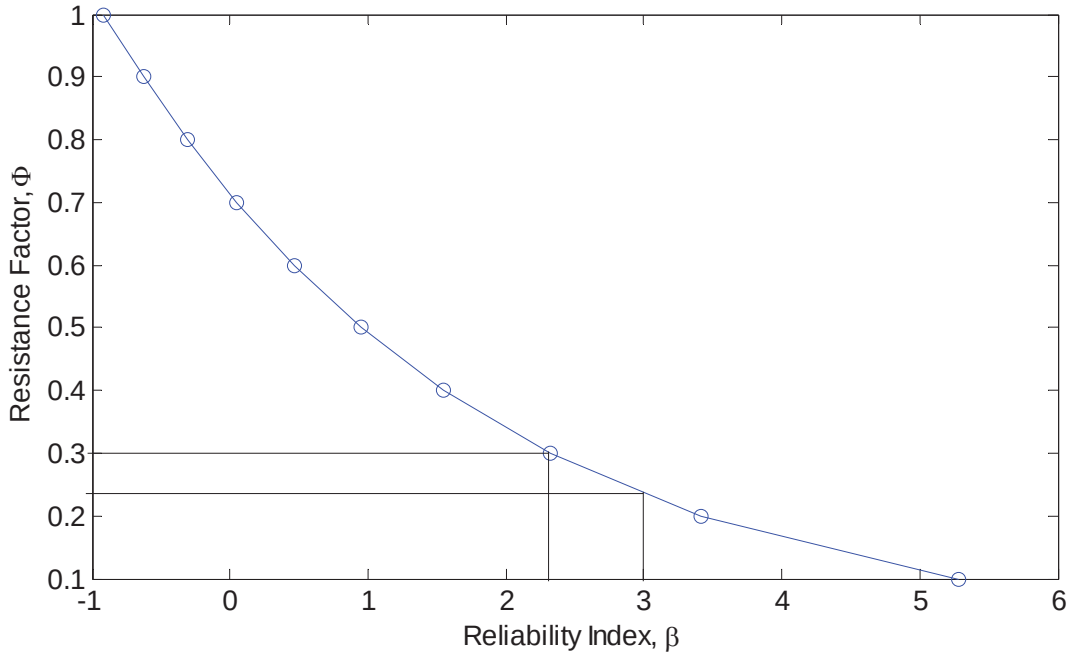


Figure F-M9-cHistogram and frequency distribution of bias factor λ9 for 99cases of concrete piles in Mixed soils using the α-Tomlinson and Nordlund/Thurman method (Su: Hara, ϕ:Schmertmann) in North of Vietnam



FigureF-M9-dResistance factor calibration for 99cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in North of Vietnam

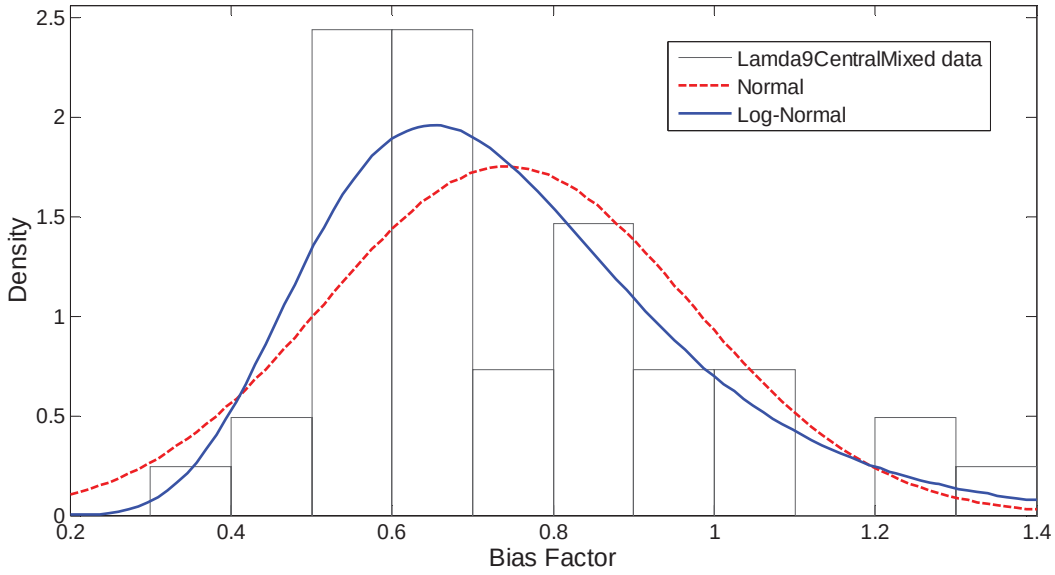


Figure F-M9-eHistogram and frequency distribution of bias factor λ9 for 41cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ:Schmertmann) in Central of Vietnam

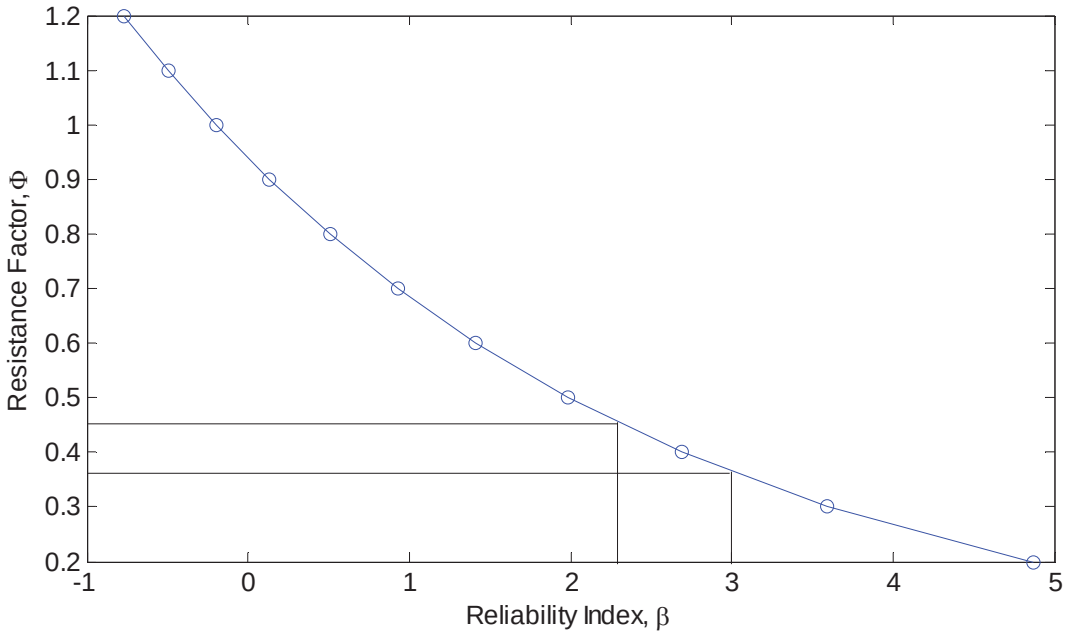


Figure F-M9-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ:Schmertmann) in Central of Vietnam

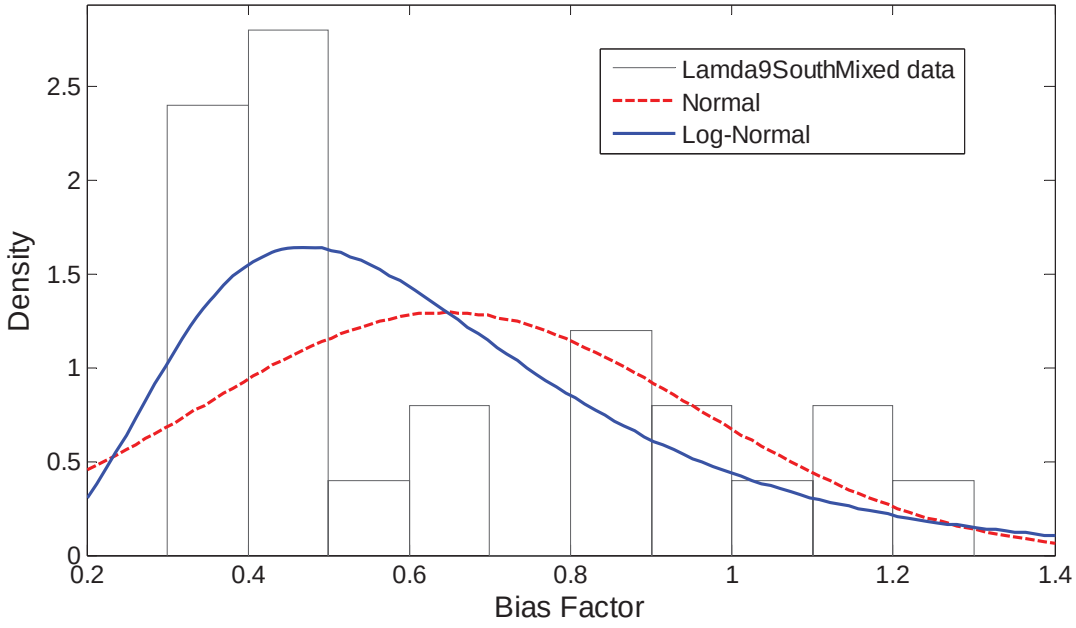


Figure F-M9-gHistogram and frequency distribution of bias factor λ9 for 25cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in South of Vietnam

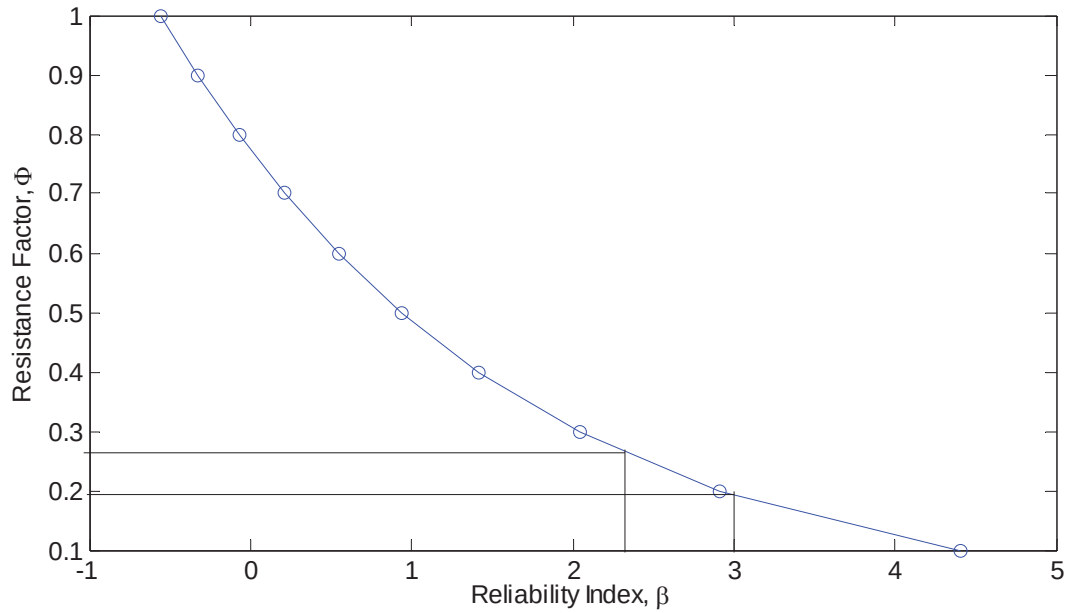


Figure F-M9-hResistance factor calibration for 25cases of concrete piles in Mixed soils using the α-Tomlinson andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in South of Vietnam

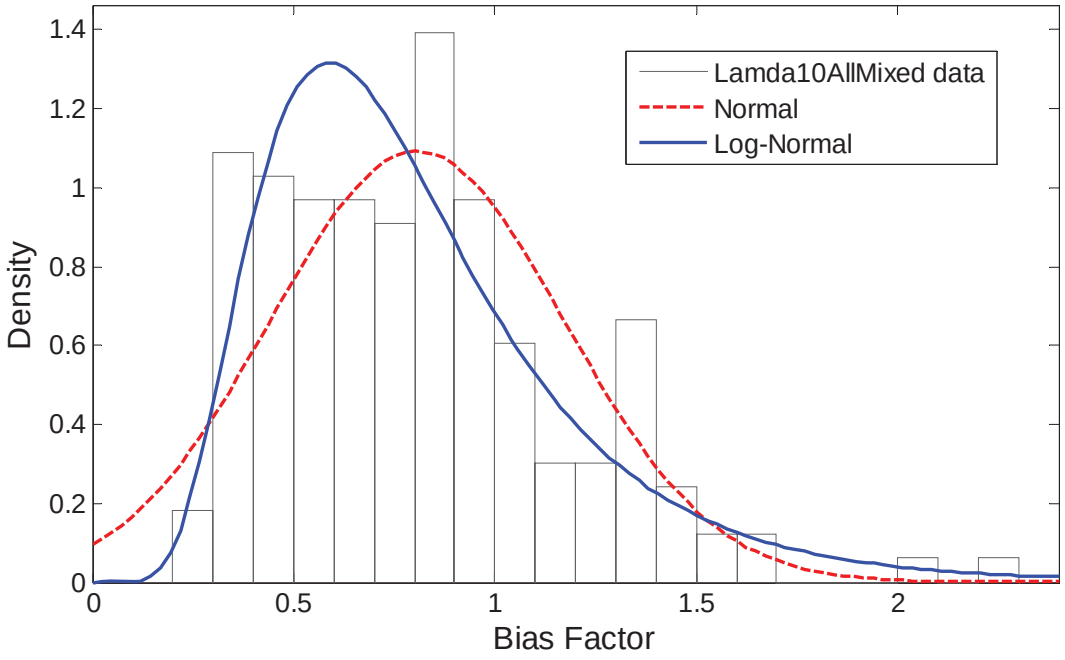


Figure F-M10-aHistogram and frequency distribution of bias factor λ10 for 165 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Vietnam

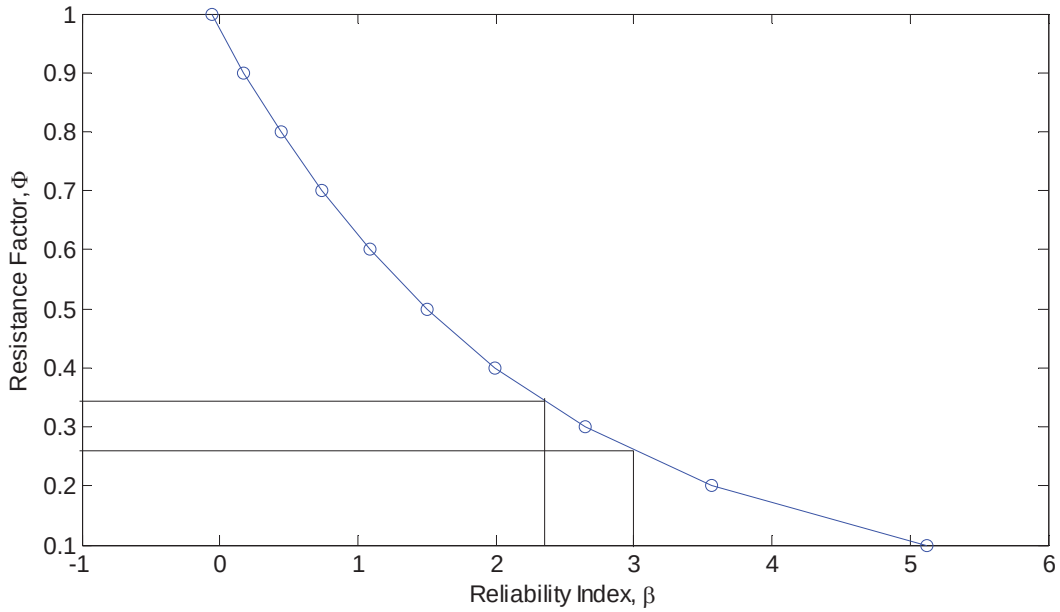


Figure F-M10-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Vietnam

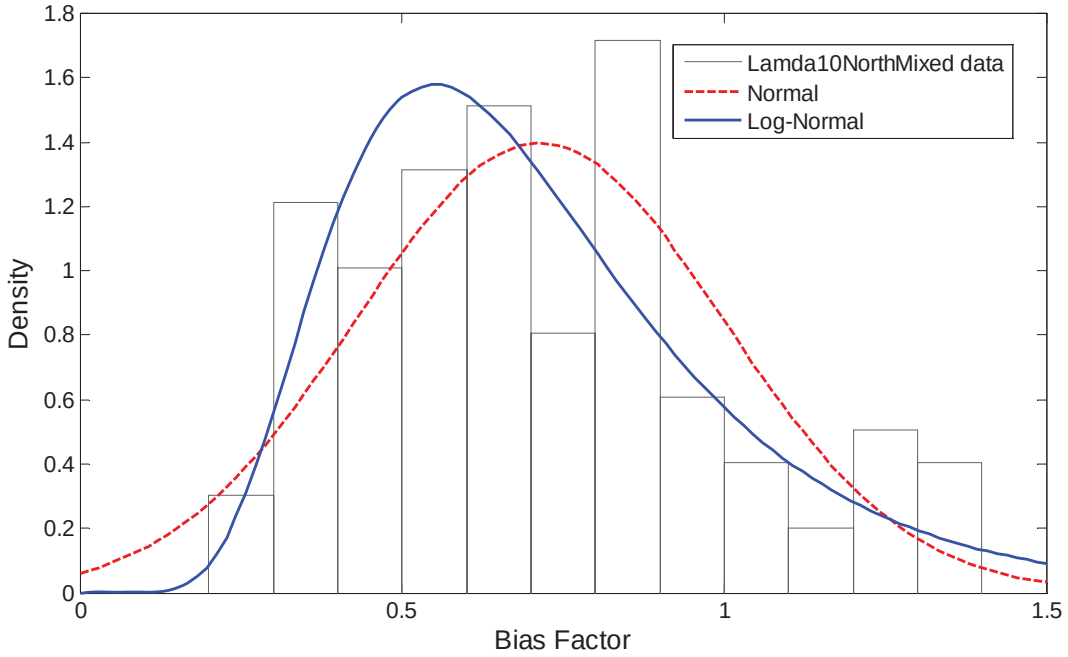


Figure F-M10-c Histogram and frequency distribution of bias factor λ10 for 99 cases of concrete piles in Mixed soils using the α-API and Nordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in North of Vietnam

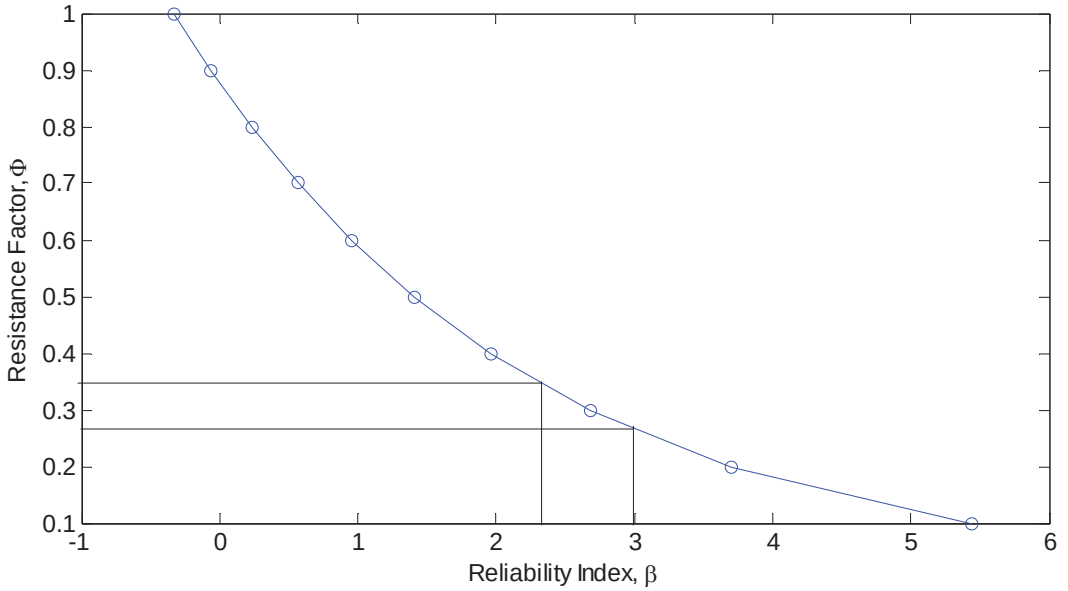


Figure F-M10-dResistance factor calibration for 99 cases of concrete piles in Mixed soils using the α-API and Nordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in North of Vietnam

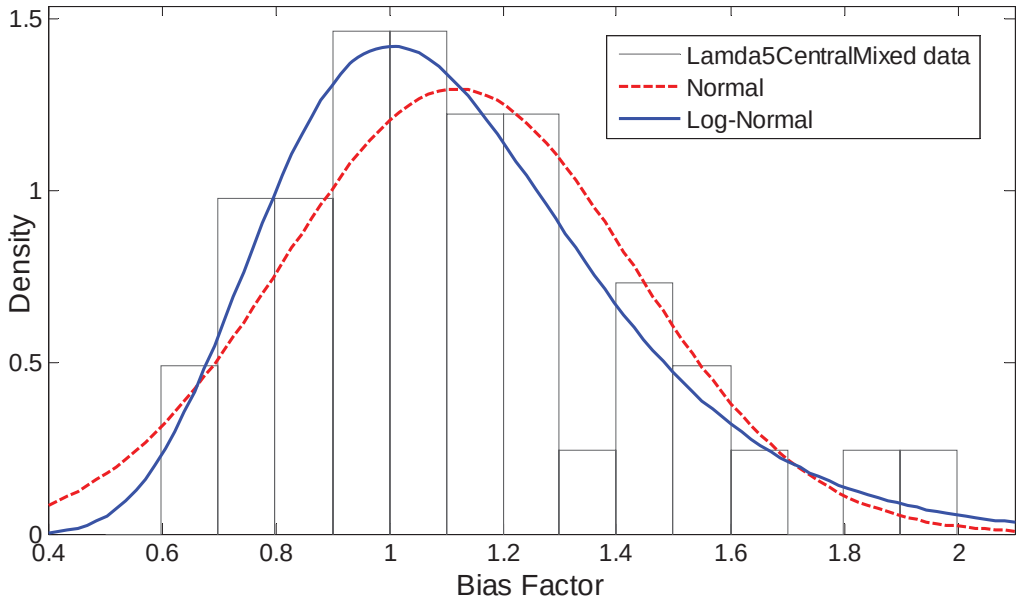


Figure F-M10-eHistogram and frequency distribution of bias factor λ10 for 41cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Central of Vietnam

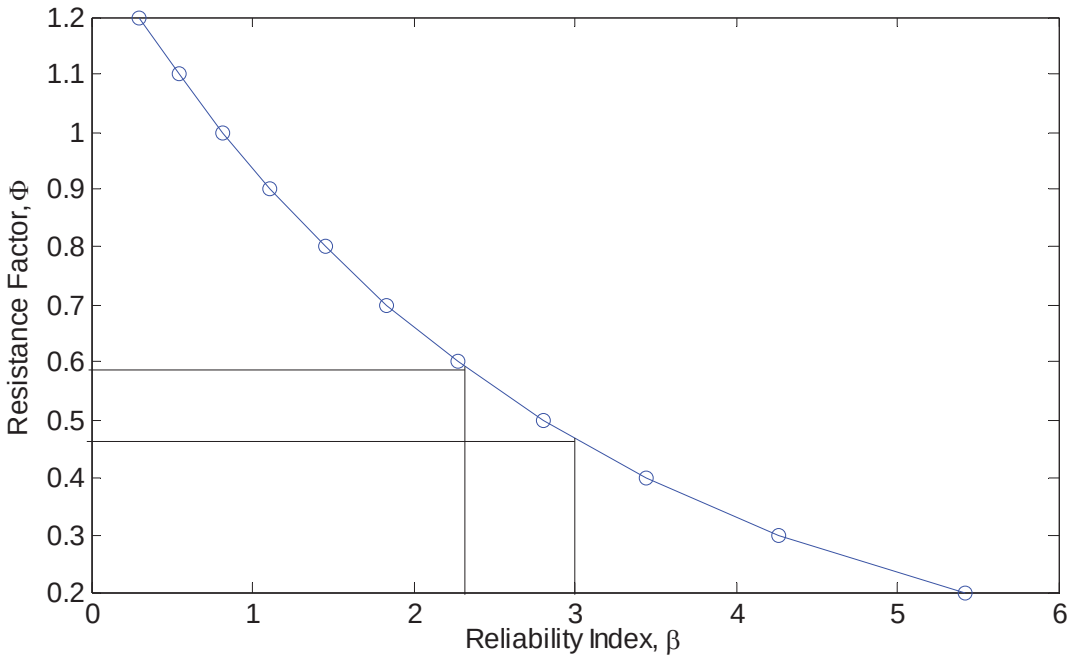


Figure F-M10-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Central of Vietnam

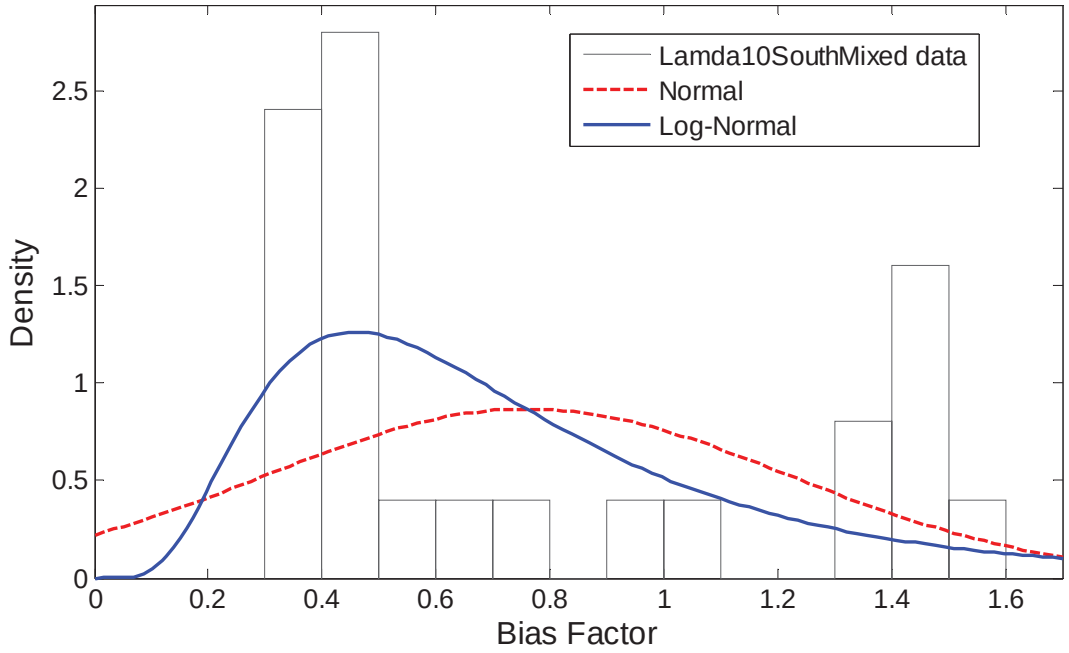


Figure F-M10-gHistogram and frequency distribution of bias factor λ10 for 25 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ:Schmertmann) in South of Vietnam

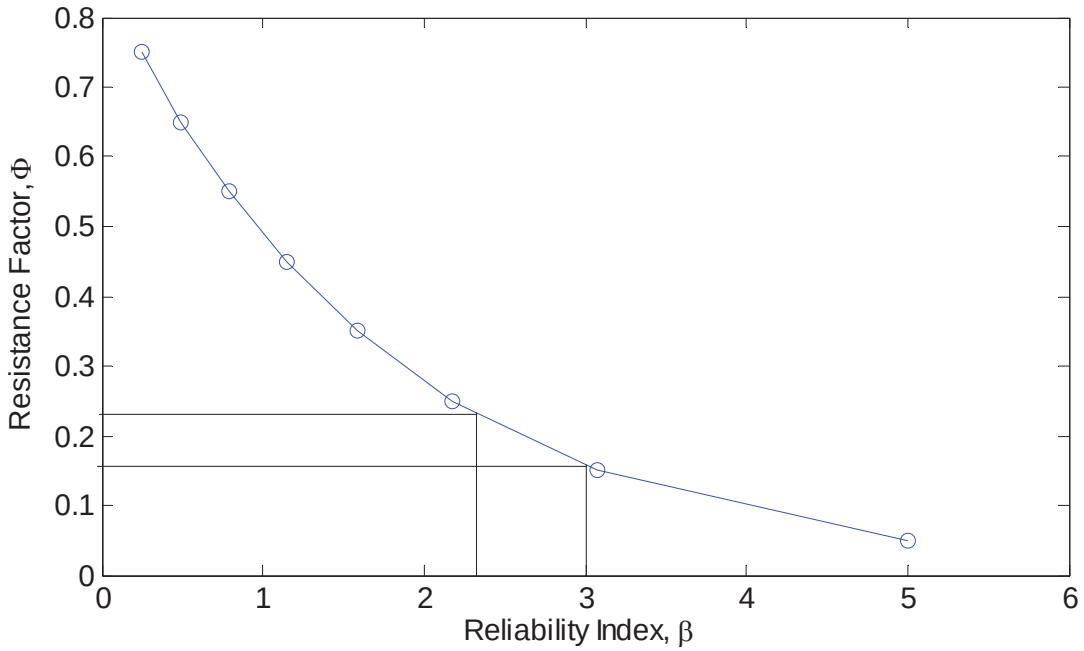


Figure F-M10-hResistance factor calibration for 25 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Peck, ϕ:Schmertmann) in South of Vietnam

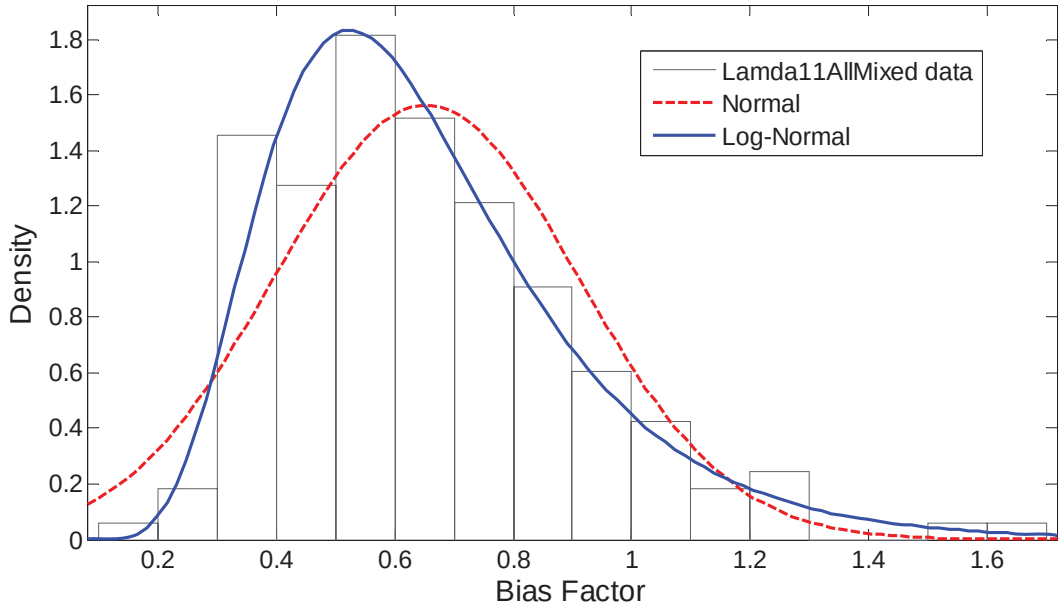


Figure F-M11-aHistogram and frequency distribution of bias factor λ11 for 165 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in Vietnam

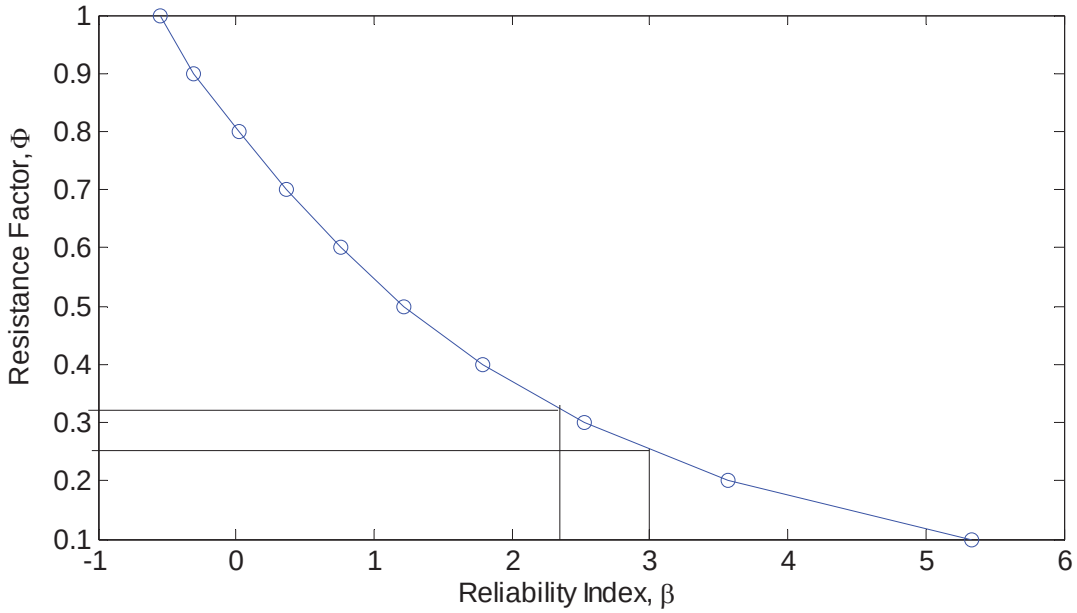


Figure F-M11-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in Vietnam

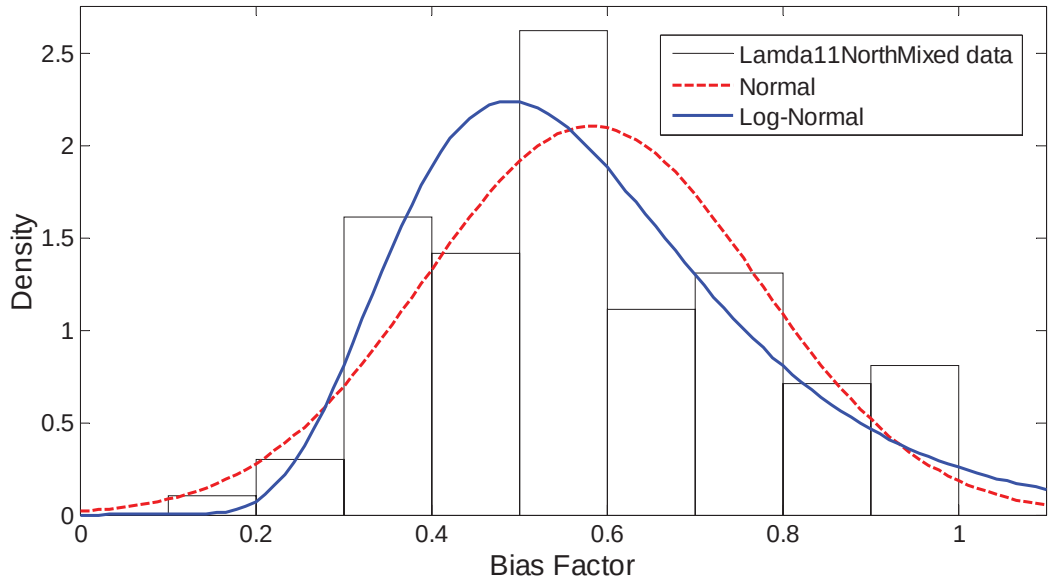


Figure F-M11-cHistogram and frequency distribution of bias factor λ11 for 99 cases of concrete piles in Mixed soils using the α-API and Nordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in North of Vietnam

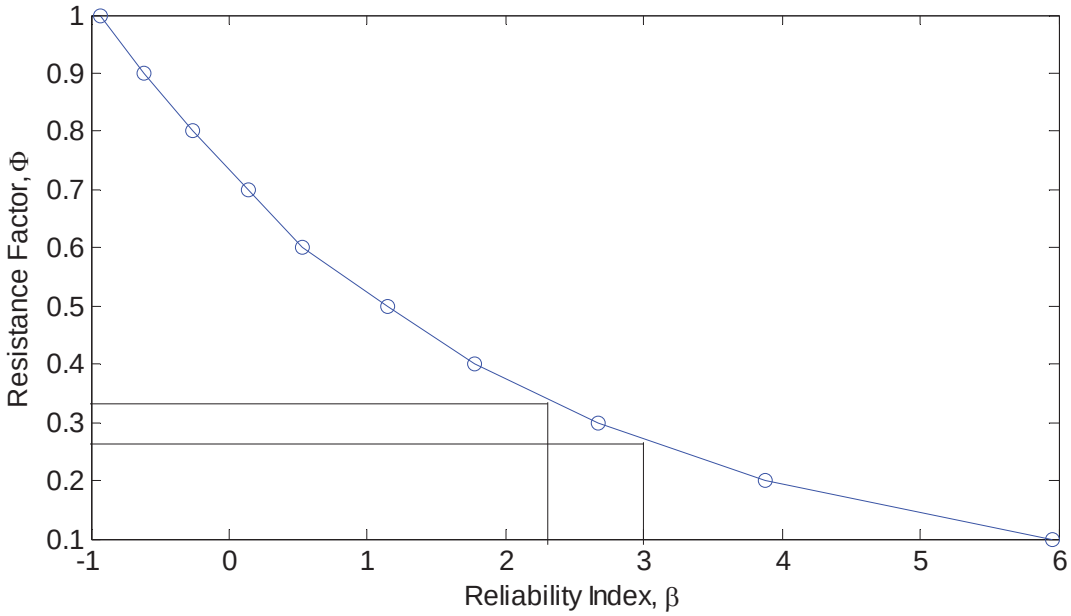


Figure F-M11-dResistance factor calibration for 99 cases of concrete piles in Mixed soils using the α-API and Nordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in North of Vietnam

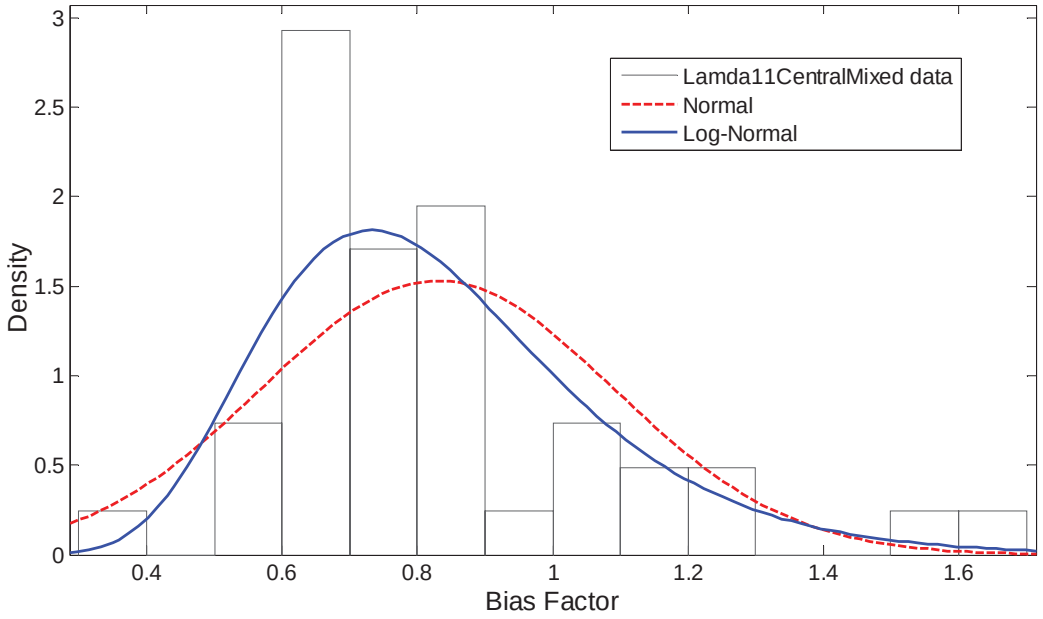


Figure F-M11-eHistogram and frequency distribution of bias factor λ11 for 41 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in Central of Vietnam

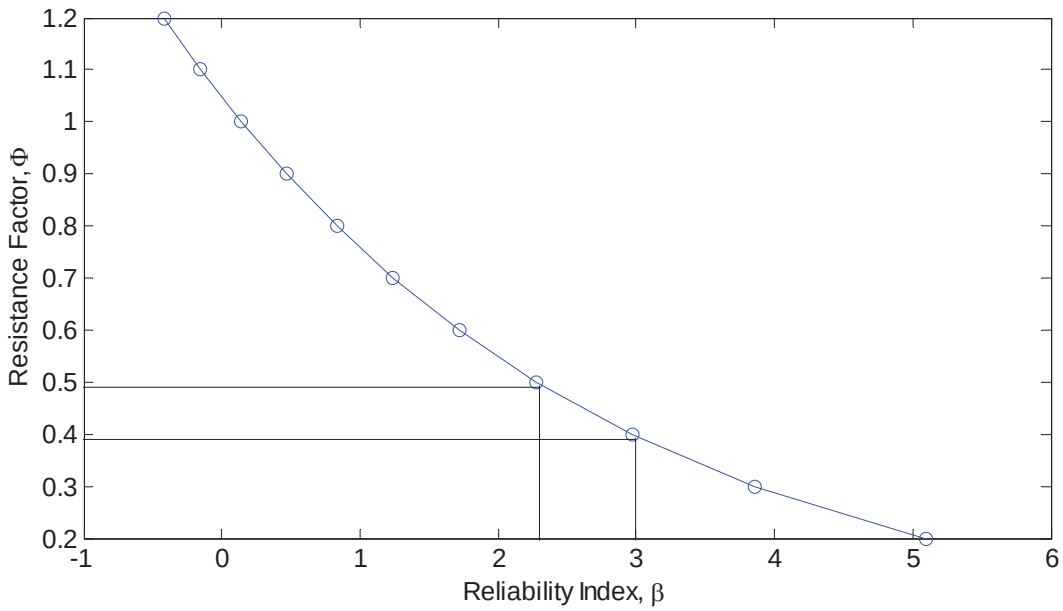


Figure F-M11-fResistance factor calibration for 41 cases of concrete piles in Mixed soils using the α-API and Nordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in Central of Vietnam

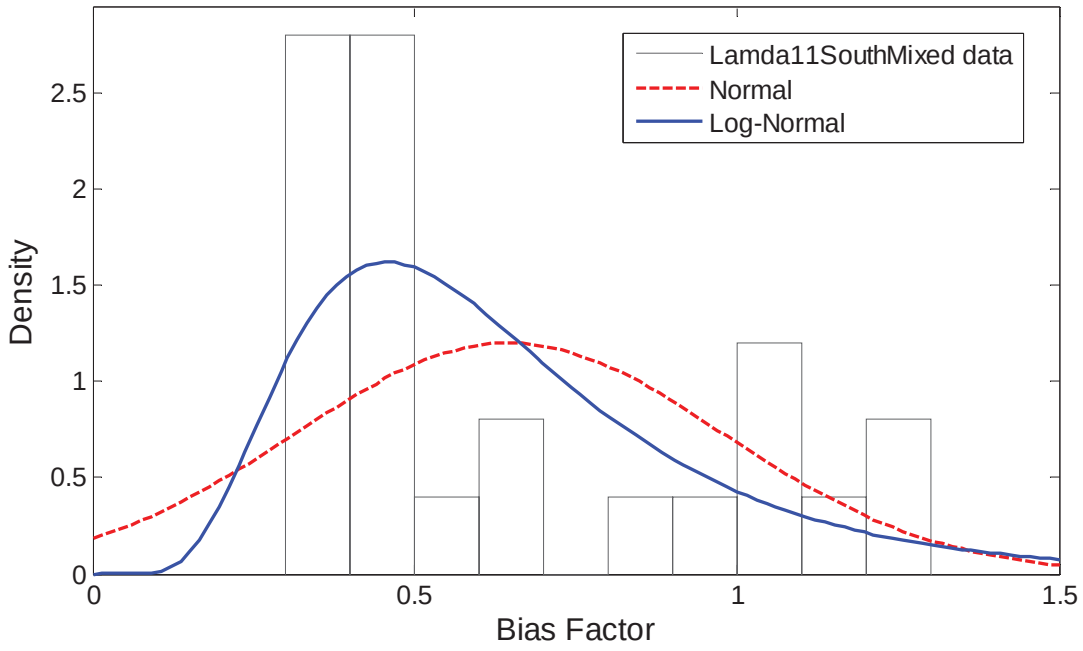


Figure F-M11-gHistogram and frequency distribution of bias factor λ11 for 25cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in South of Vietnam

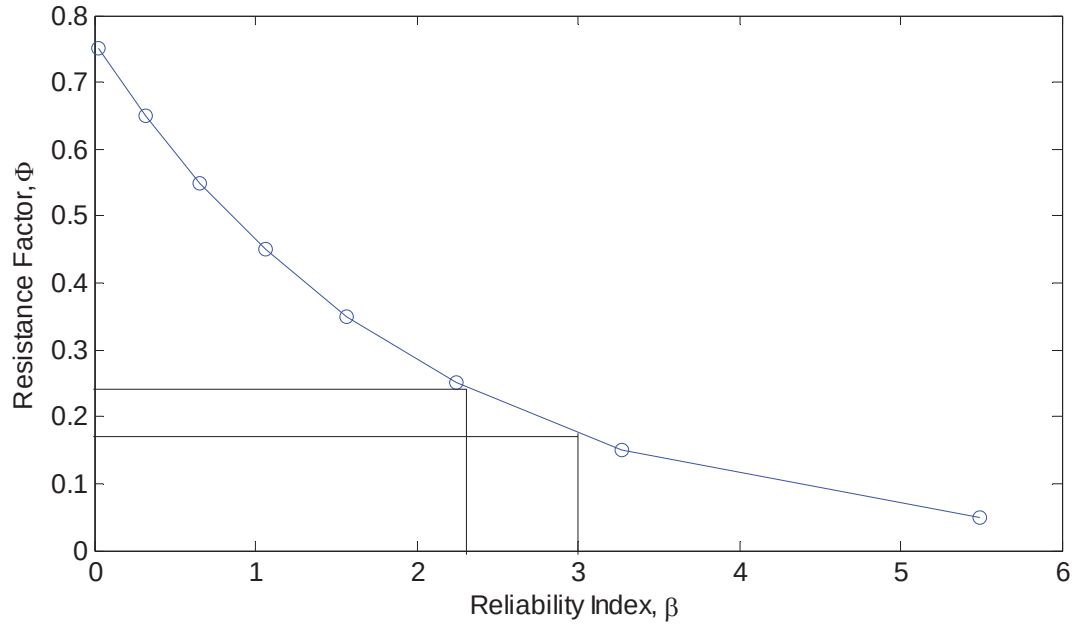


Figure F-M11-h Resistance factor calibration for 25 cases of concrete piles in Mixed soils using the α-API andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in South of Vietnam

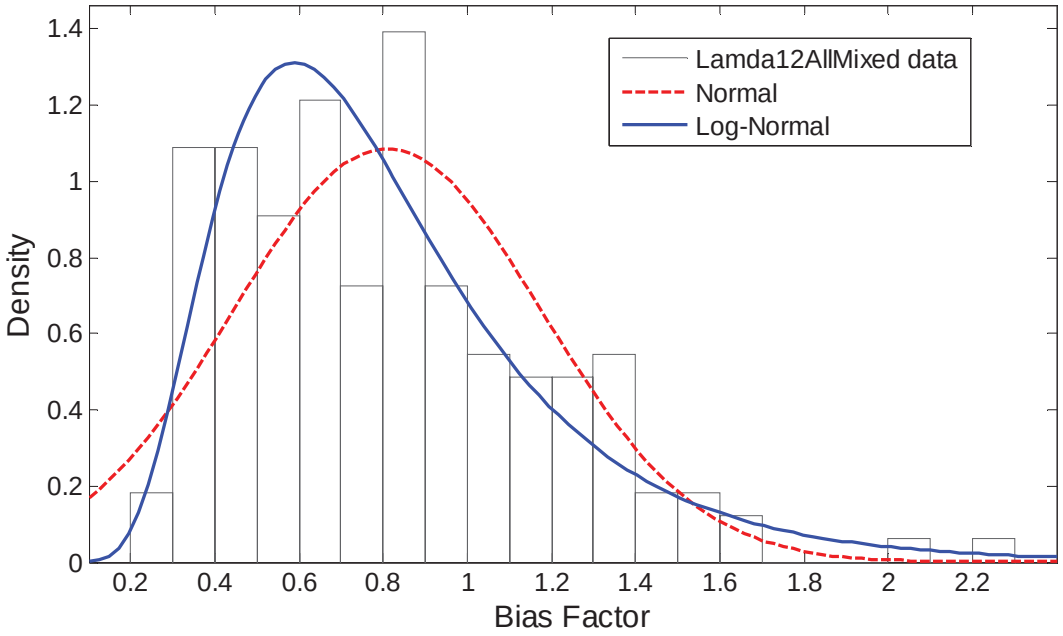


Figure F-M12-aHistogram and frequency distribution of bias factor λ12 for 165 cases of concrete piles in Mixed soils using the λ and Nordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Vietnam

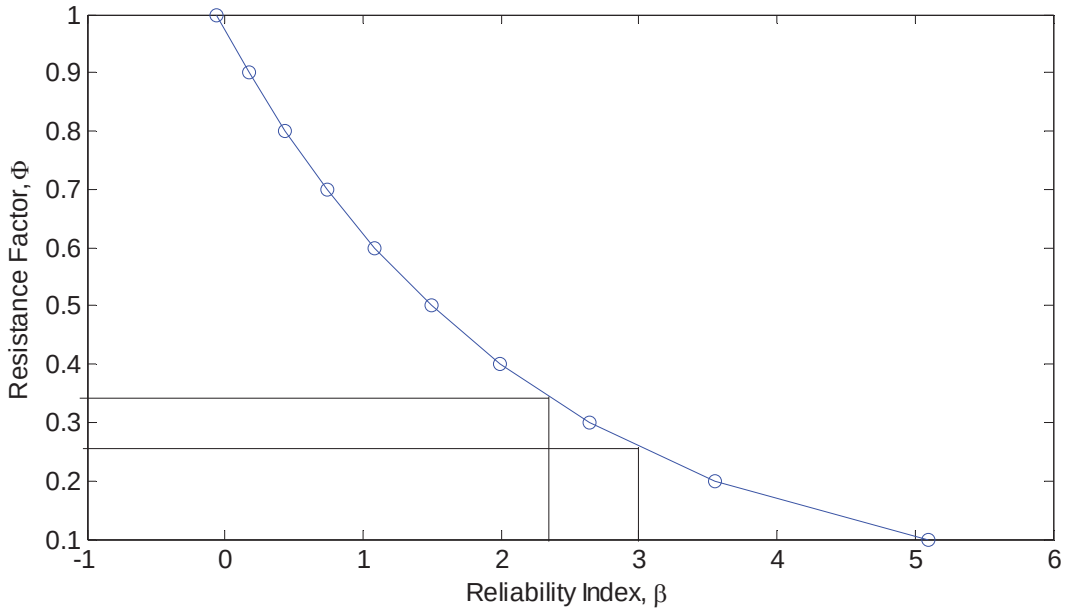


Figure F-M12-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Vietnam

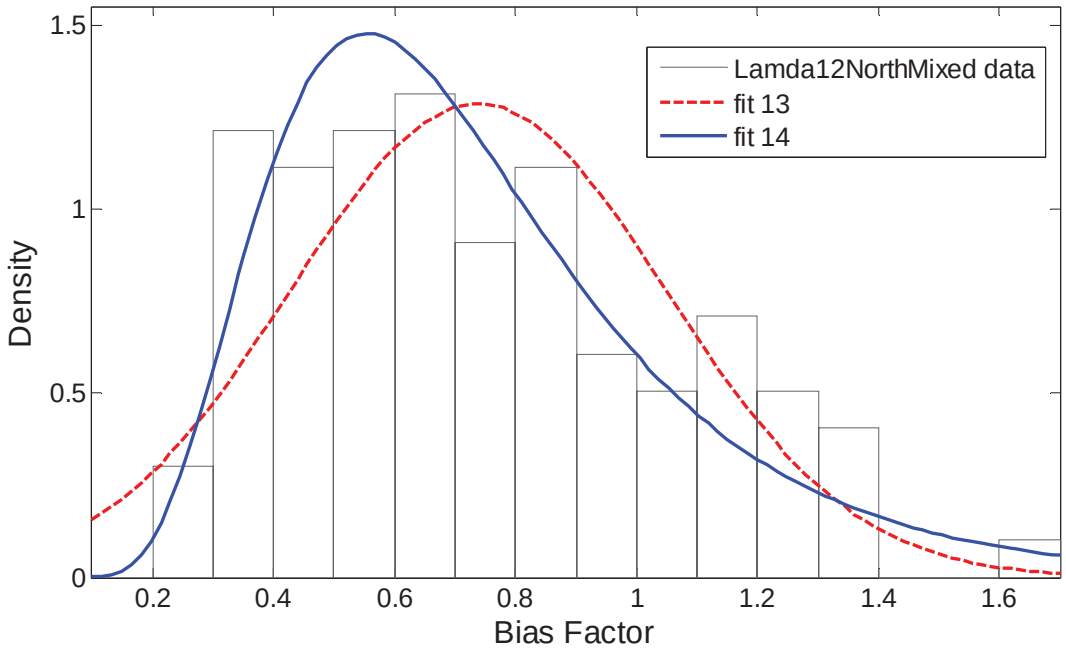


Figure F-M12-cHistogram and frequency distribution of bias factor λ12 for 99 cases of concrete piles in Mixed soils using the λ and Nordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in North of Vietnam

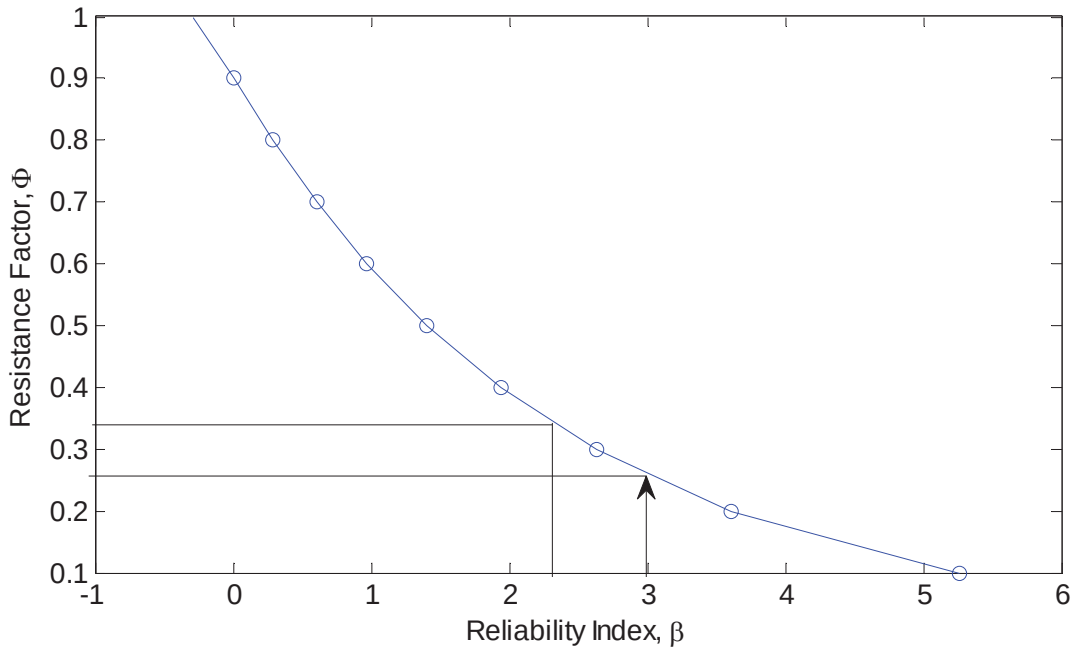


Figure F-M12-dResistance factor calibration for 99 cases of concrete piles in Mixed soils using the λ and Nordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in North of Vietnam

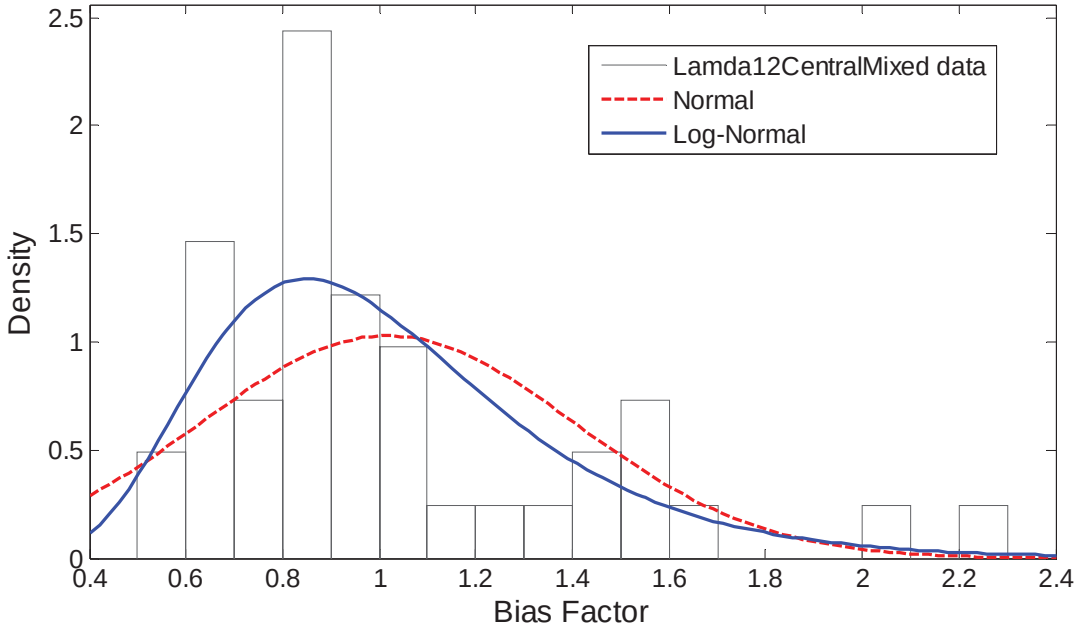


Figure F-M12-eHistogram and frequency distribution of bias factor λ12 for 41 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Central of Vietnam

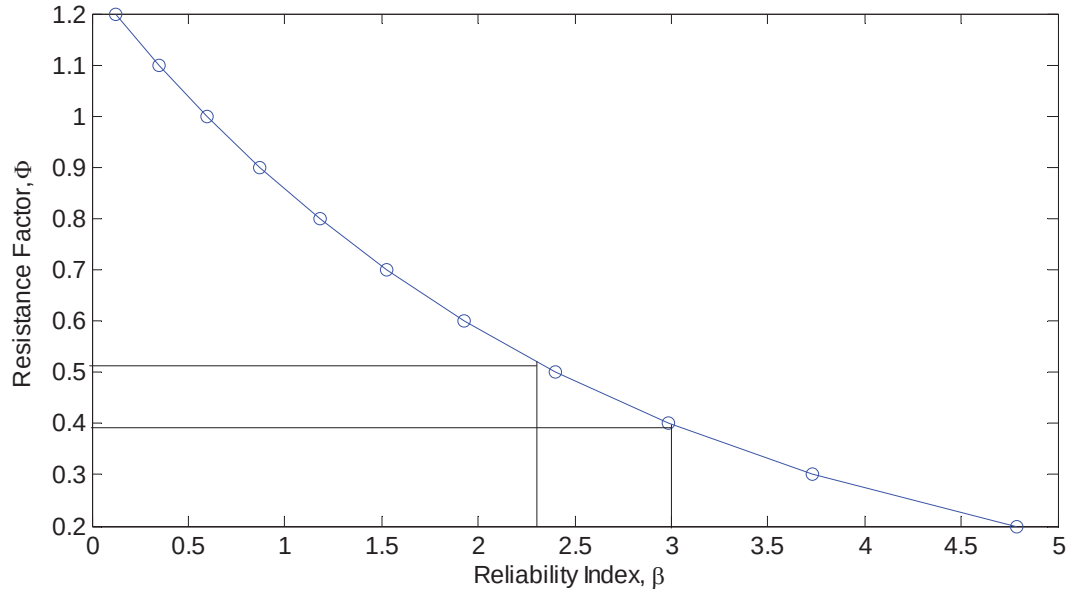


Figure F-M12-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in Central of Vietnam

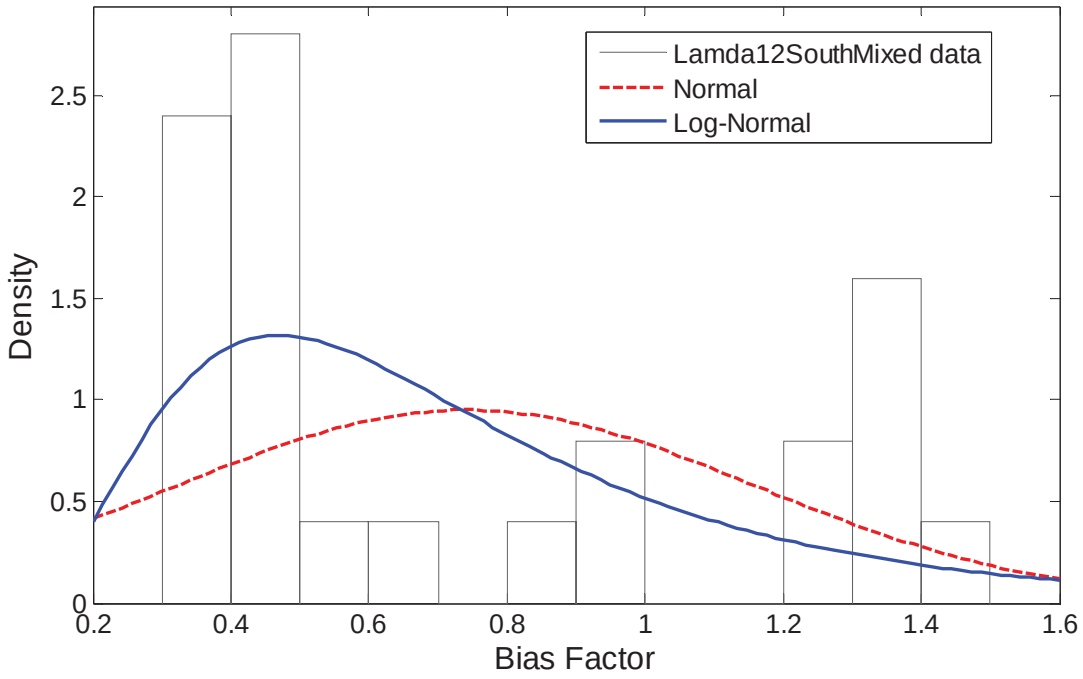


Figure F-M12-gHistogram and frequency distribution of bias factor λ12 for 25cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in South of Vietnam

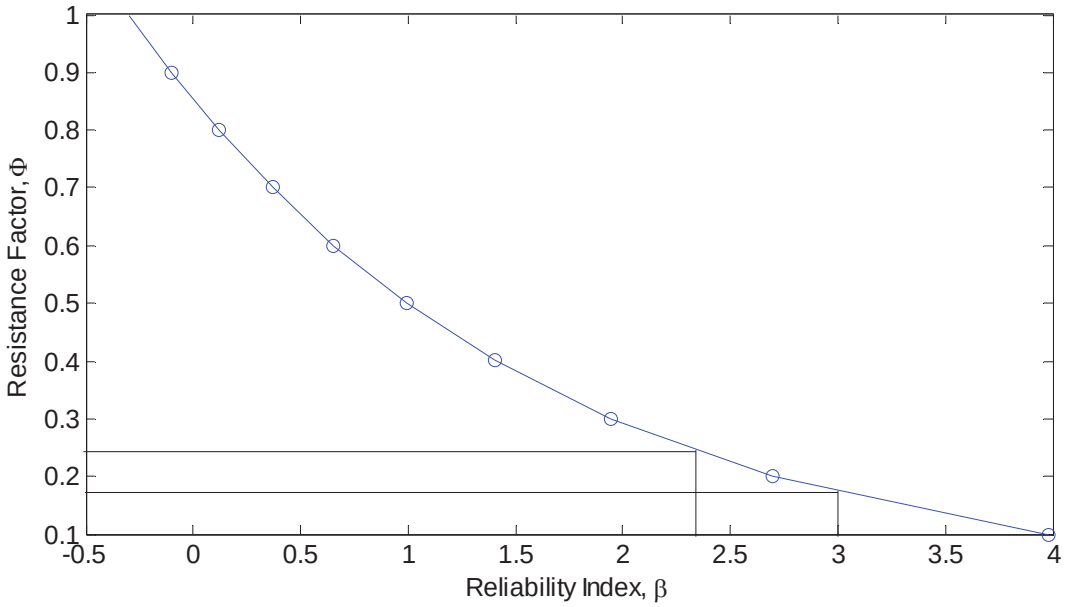


Figure F-M12-hResistance factor calibration for 25 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Peck, ϕ: Schmertmann) in South of Vietnam

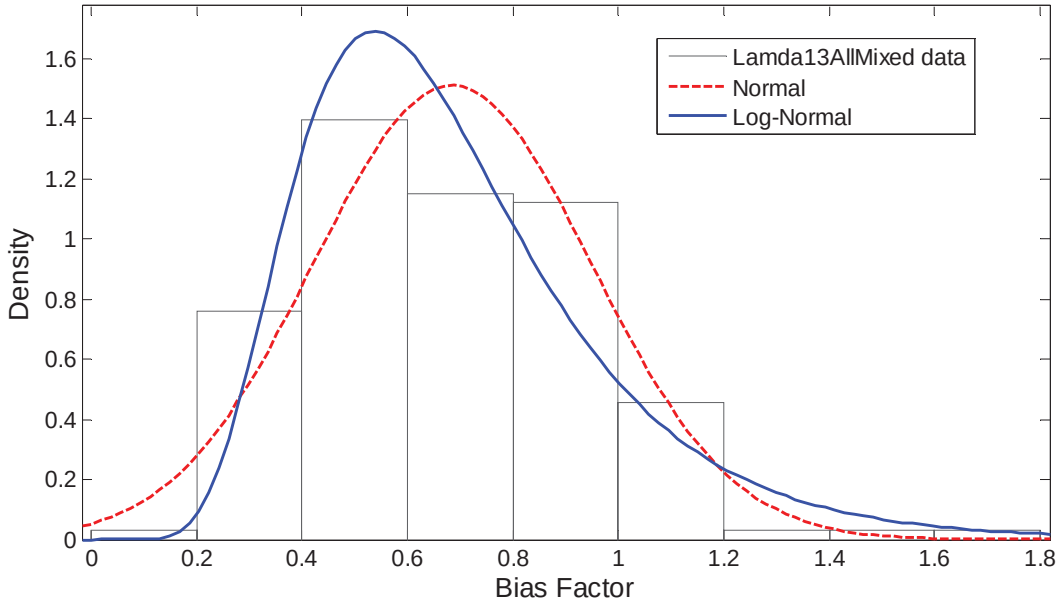


Figure F-M13-aHistogram and frequency distribution of bias factor λ13 for 165 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in Vietnam

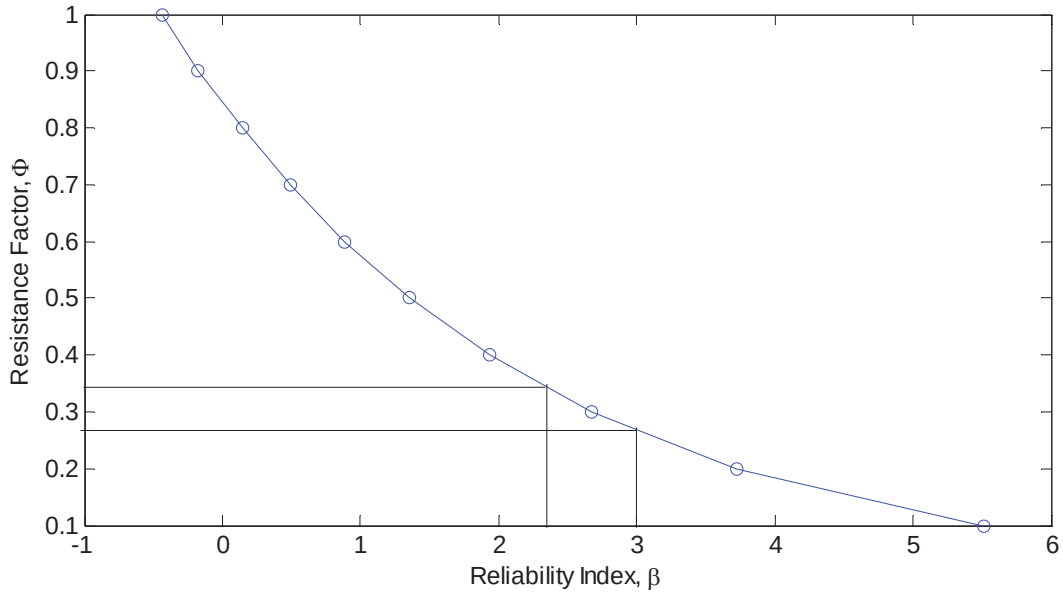


Figure F-M13-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in Vietnam

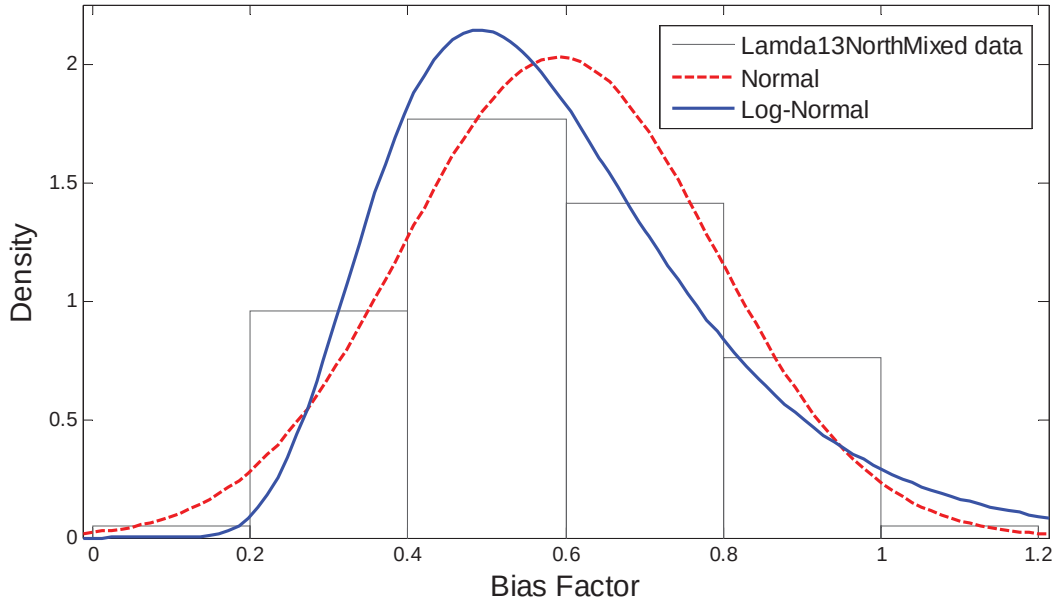


Figure F-M13-cHistogram and frequency distribution of bias factor λ13 for 99 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in North of Vietnam

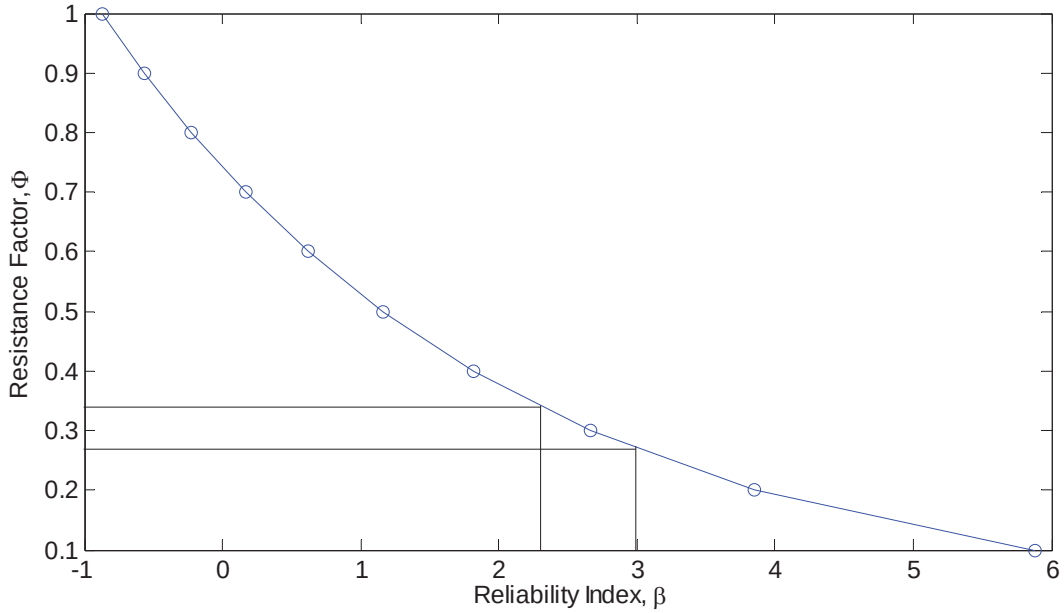


Figure F-M13-dResistance factor calibration for 99cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in North of Vietnam

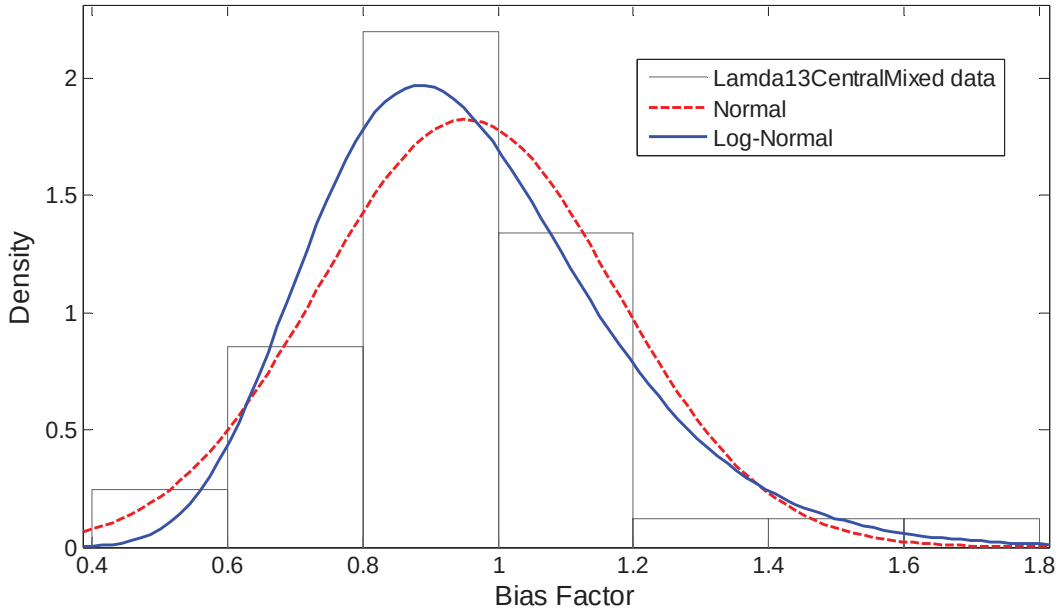


Figure F-M13-eHistogram and frequency distribution of bias factor λ13 for 41 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in Central of Vietnam

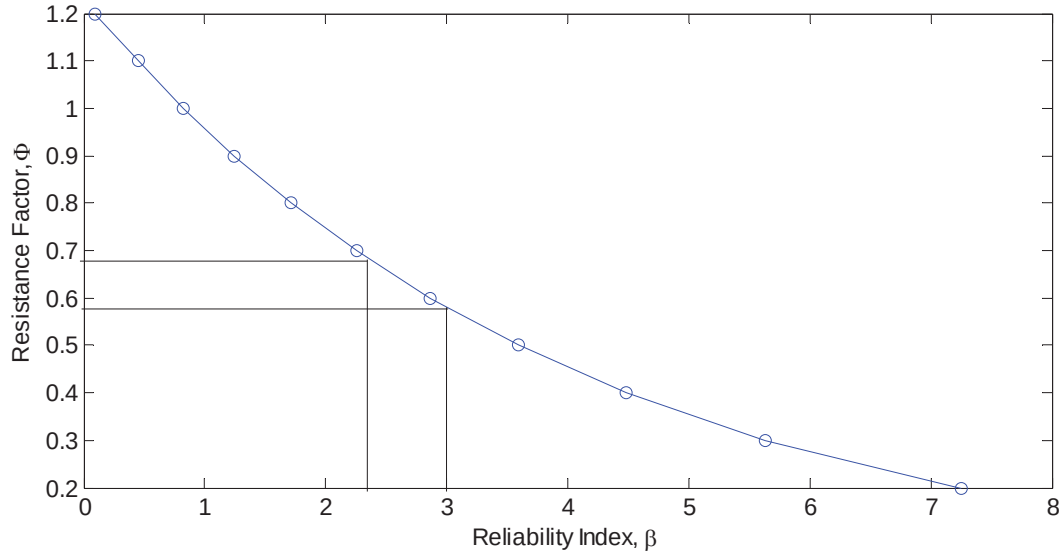


Figure F-M13-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in Central of Vietnam

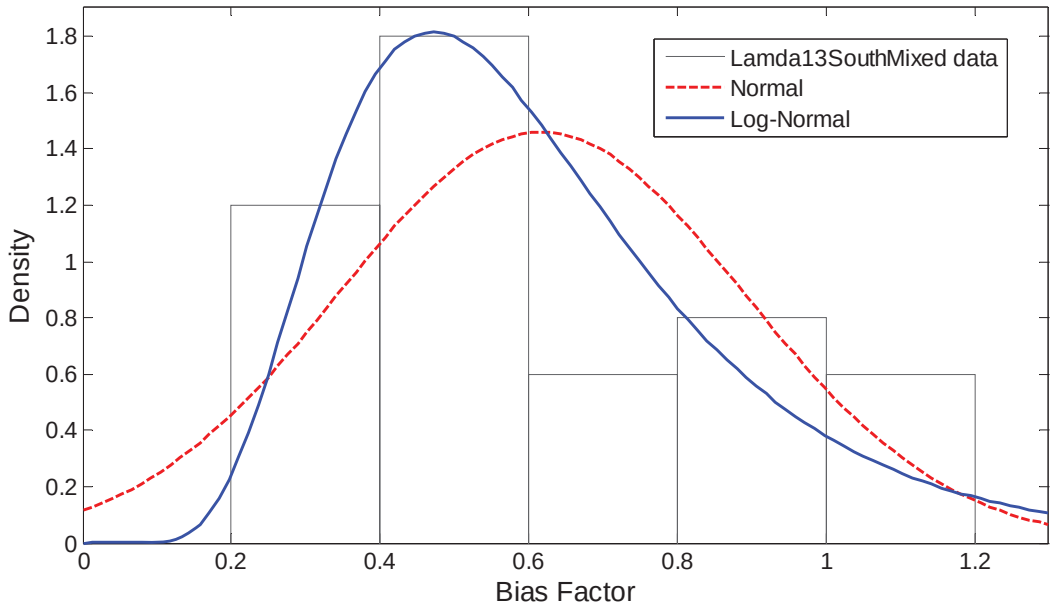


Figure F-M13-gHistogram and frequency distribution of bias factor λ13 for 25 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in South of Vietnam

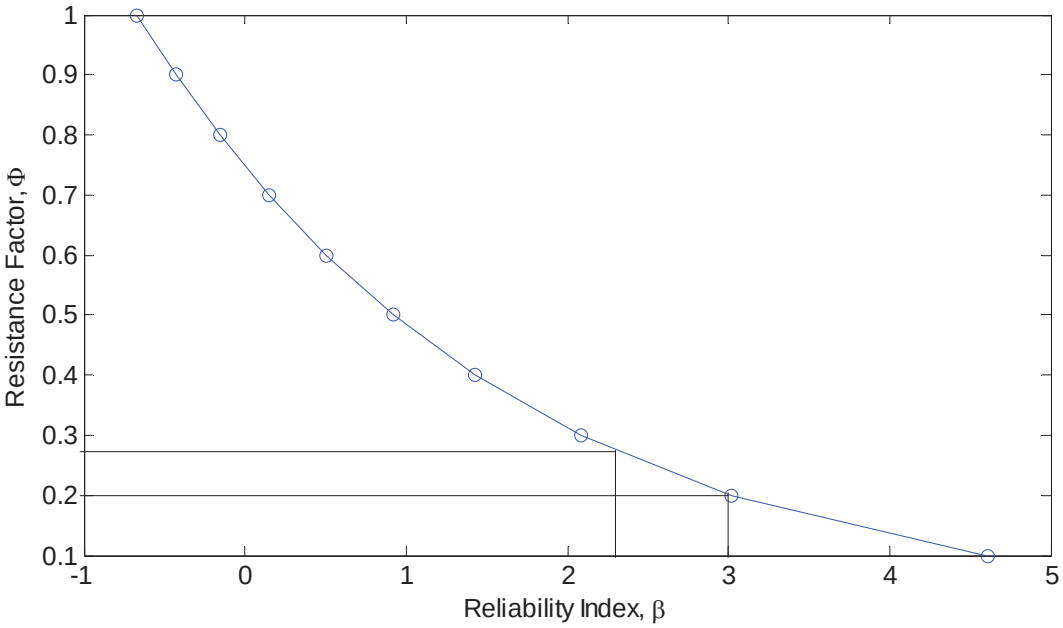


Figure F-M13-hResistance factor calibration for 25 cases of concrete piles in Mixed soils using the λ andNordlund/Thurman method (Su: Hara, ϕ: Schmertmann) in South of Vietnam

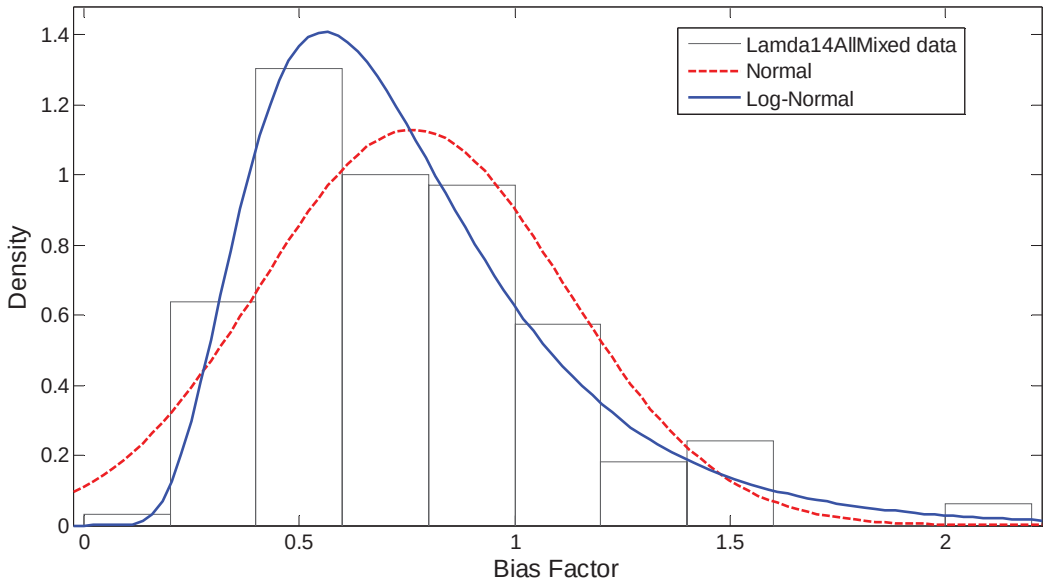


Figure F-M14-aHistogram and frequency distribution of bias factor λ14 for 165 cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ: Schmertmann) in Vietnam

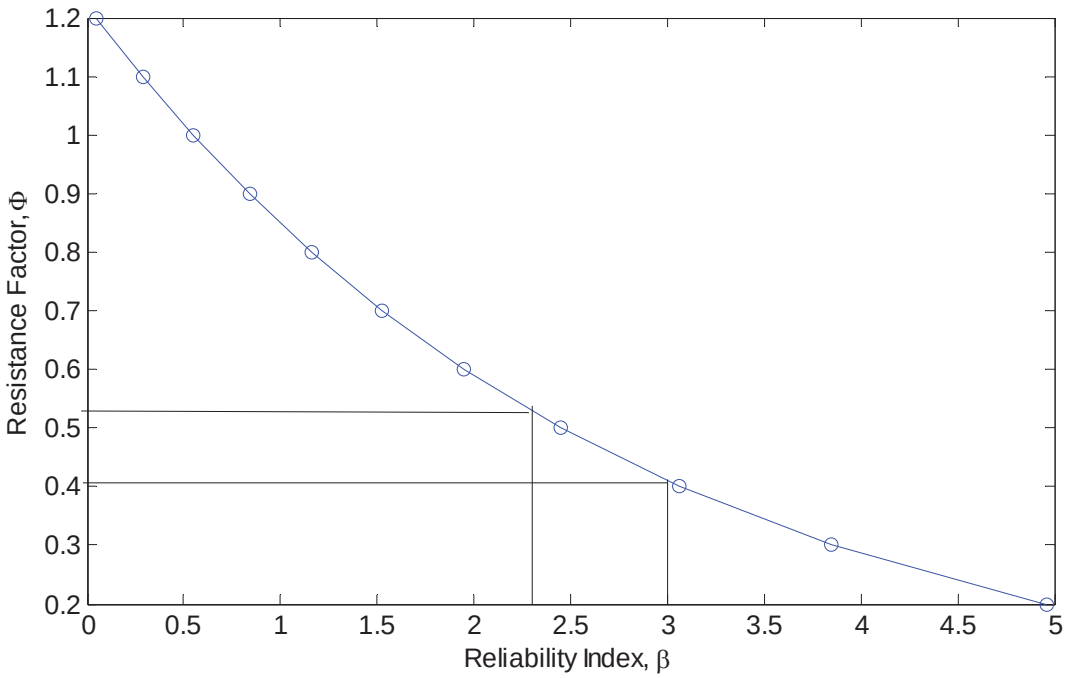


Figure F-M14-bResistance factor calibration for 165 cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ: Schmertmann) in Vietnam

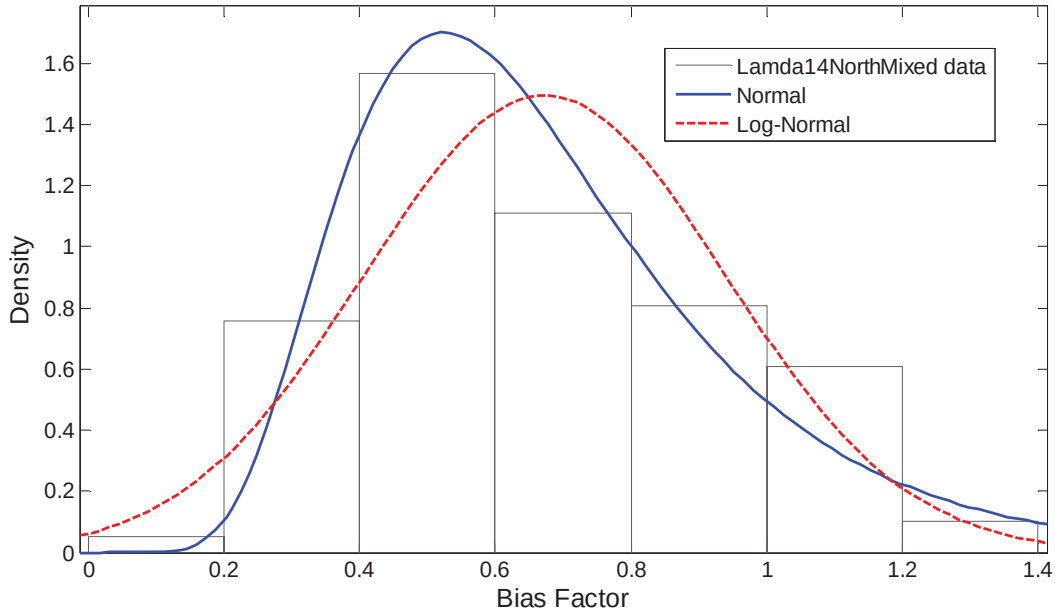


Figure F-M14-c Histogram and frequency distribution of bias factor λ14 for 99 cases of concrete piles in Mixed soils using the βBurland and Nordlund/Thurman method (ϕ:Schmertmann) in North of Vietnam

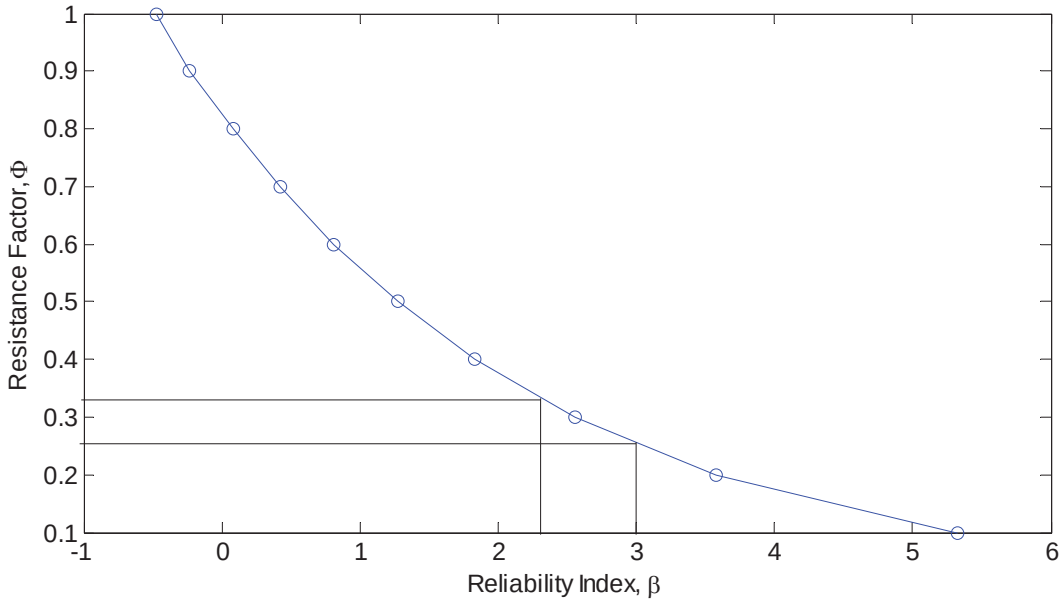


Figure F-M14-dResistance factor calibration for 99 cases of concrete piles in Mixed soils using the βBurland and Nordlund/Thurman method (ϕ:Schmertmann) in North of Vietnam

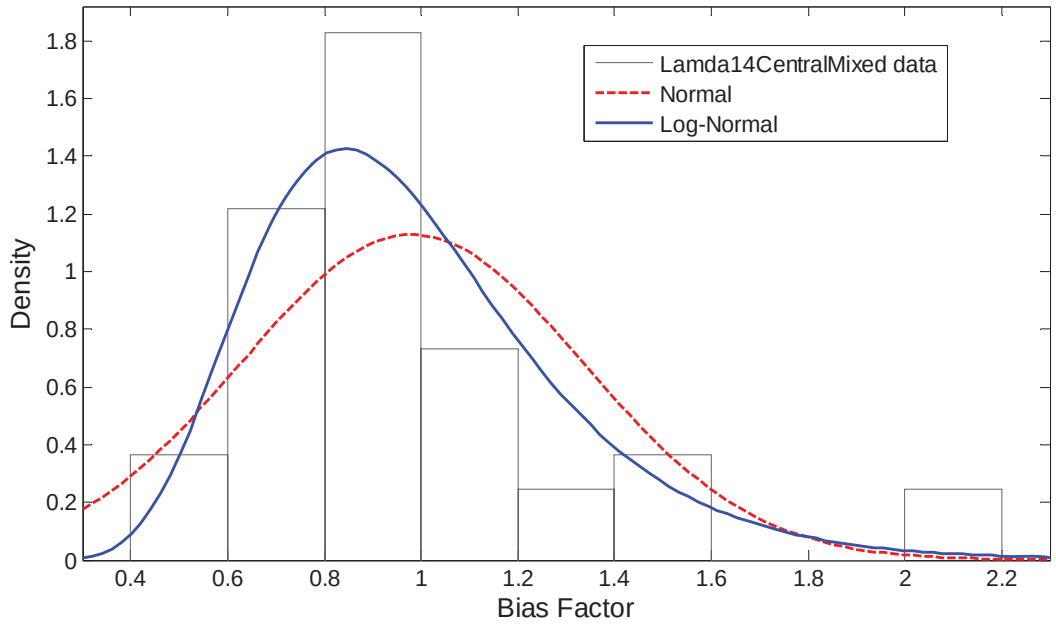


Figure F-M14-eHistogram and frequency distribution of bias factor λ14 for 41cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ:Schmertmann) in Central of Vietnam

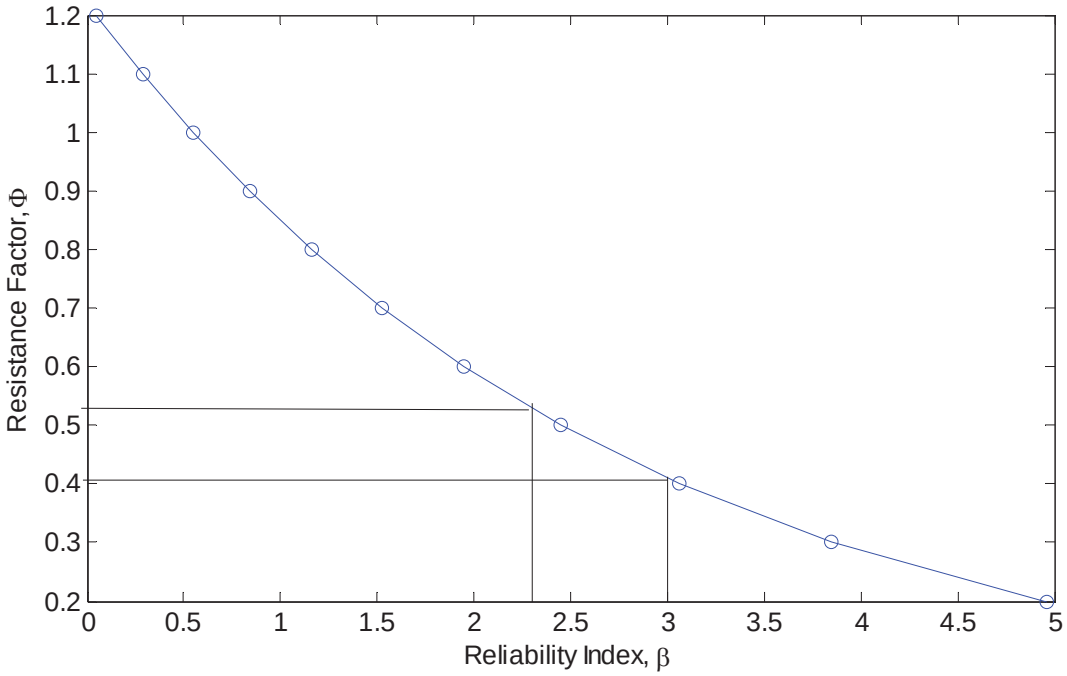


Figure F-M14-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ:Schmertmann) in Central of Vietnam

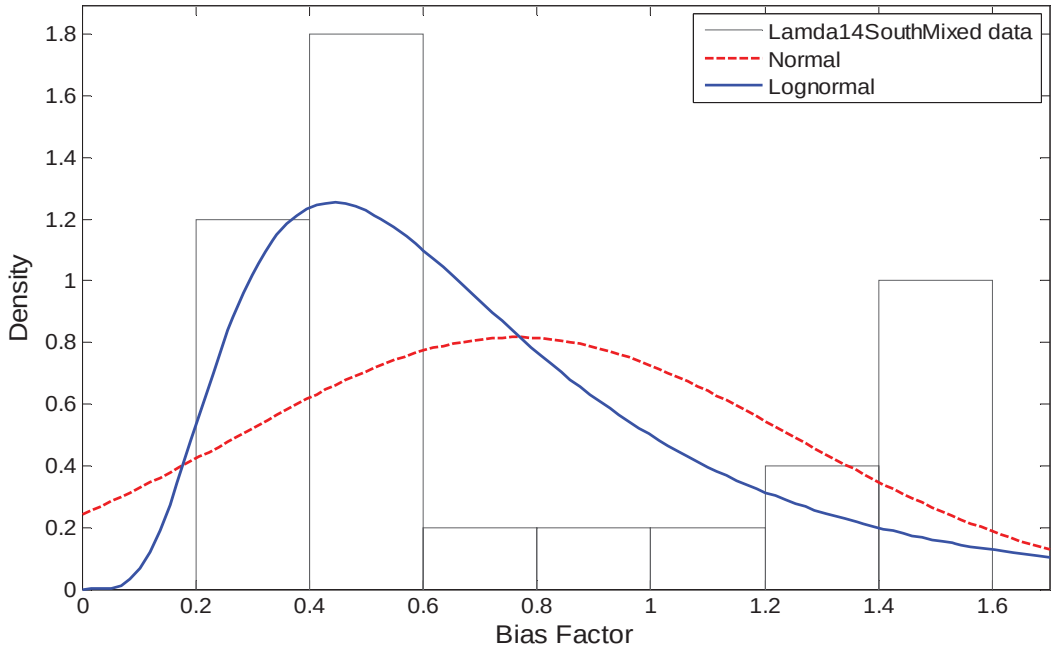


Figure F-M14-gHistogram and frequency distribution of bias factor λ14 for 25cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ:Schmertmann) in South of Vietnam

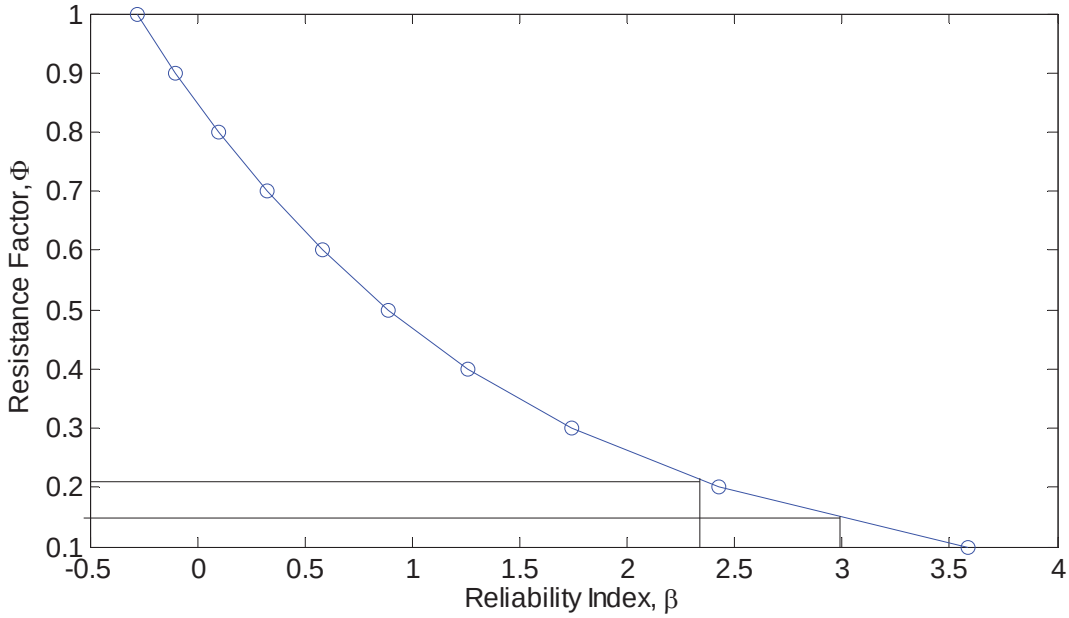


Figure F-M14-hResistance factor calibration for 25cases of concrete piles in Mixed soils using the βBurland andNordlund/Thurman method (ϕ:Schmertmann) in South of Vietnam

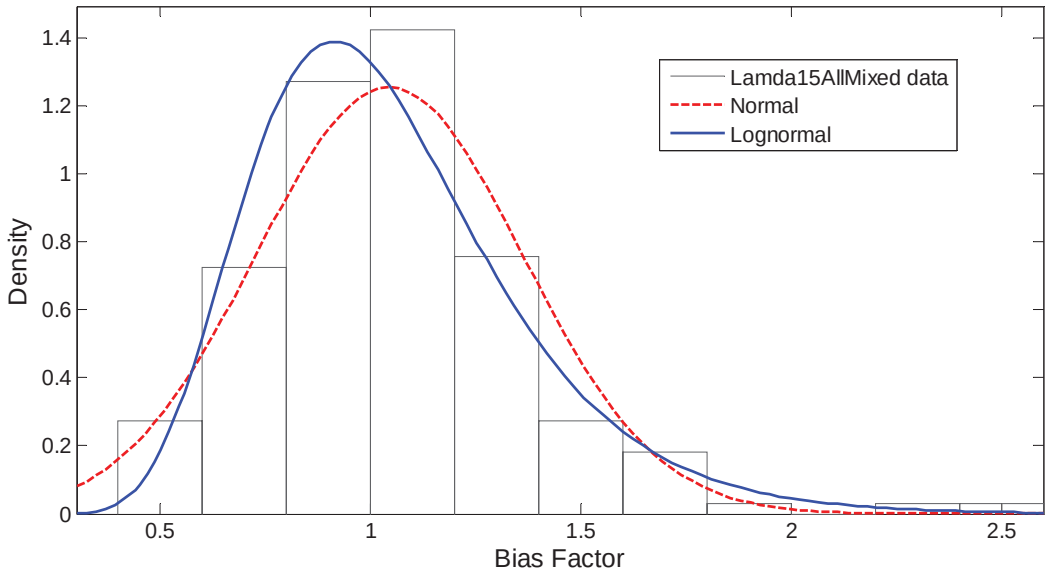


Figure F-M15-aHistogram and frequency distribution of bias factor λ15 for 165cases of concrete piles in Mixed soils using the Schmertmann SPT method in Vietnam

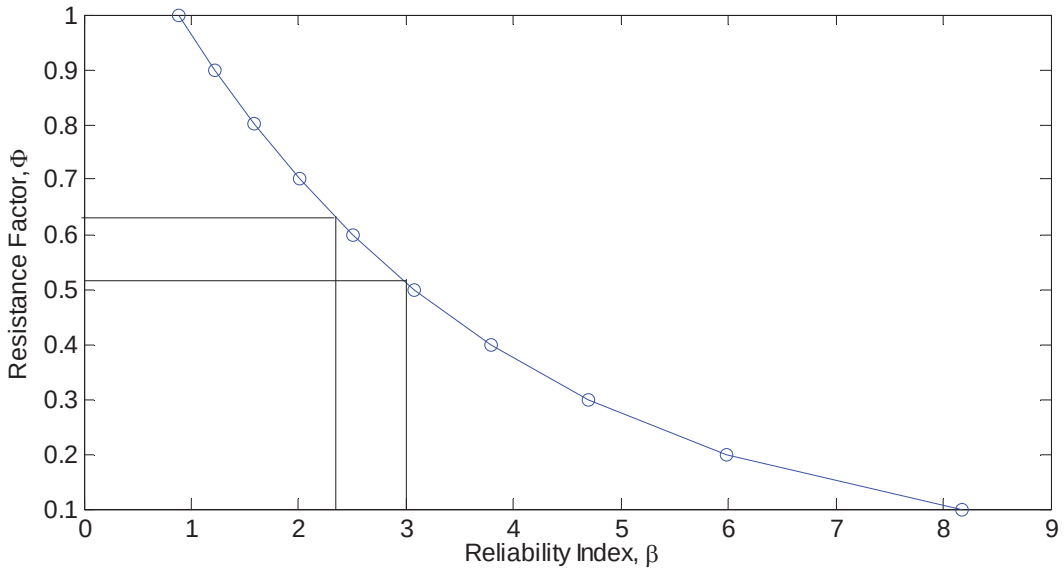


Figure F-M15-bResistance factor calibration for 165cases of concrete piles in Mixed soils using the Schmertmann SPT method in Vietnam

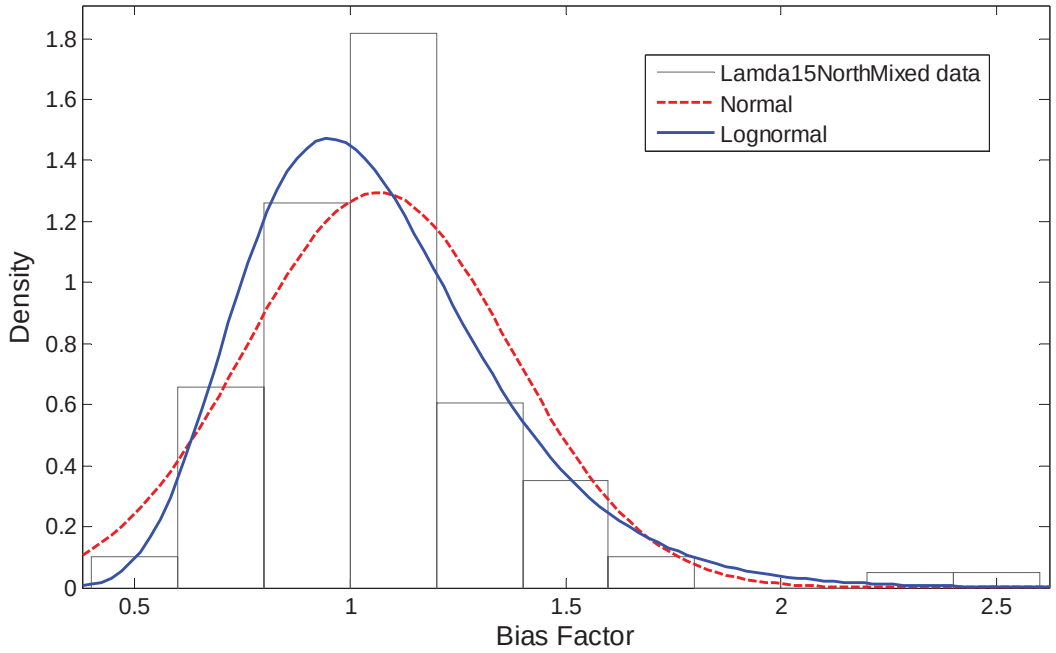


Figure F-M15-cHistogram and frequency distribution of bias factor λ15 for 99 cases of concrete piles in Mixed soils using the Schmertmann SPT method in North of Vietnam

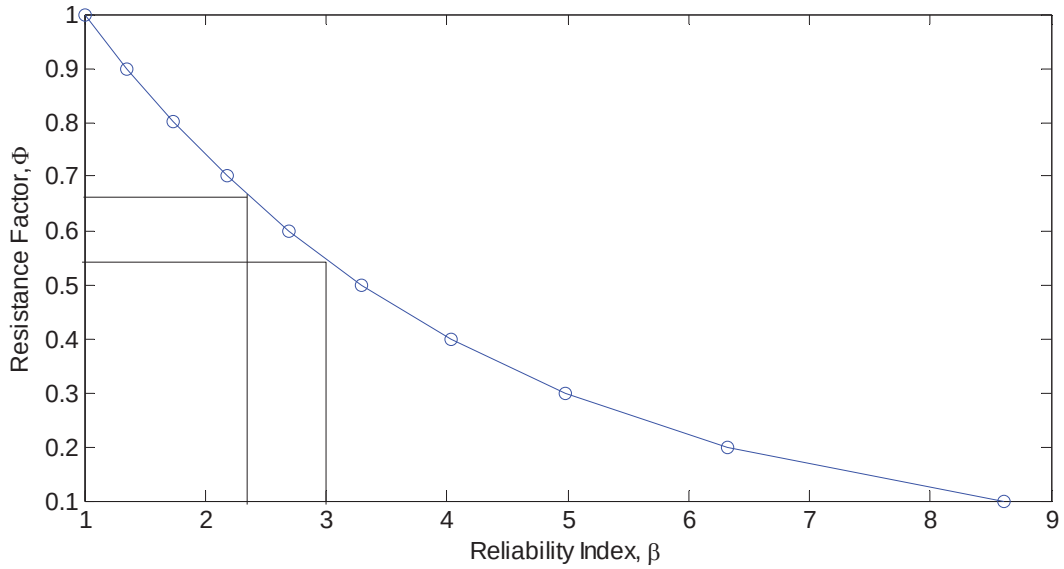


Figure F-M15-dResistance factor calibration for 99 cases of concrete piles in Mixed soils using the Schmertmann SPT method in North of Vietnam

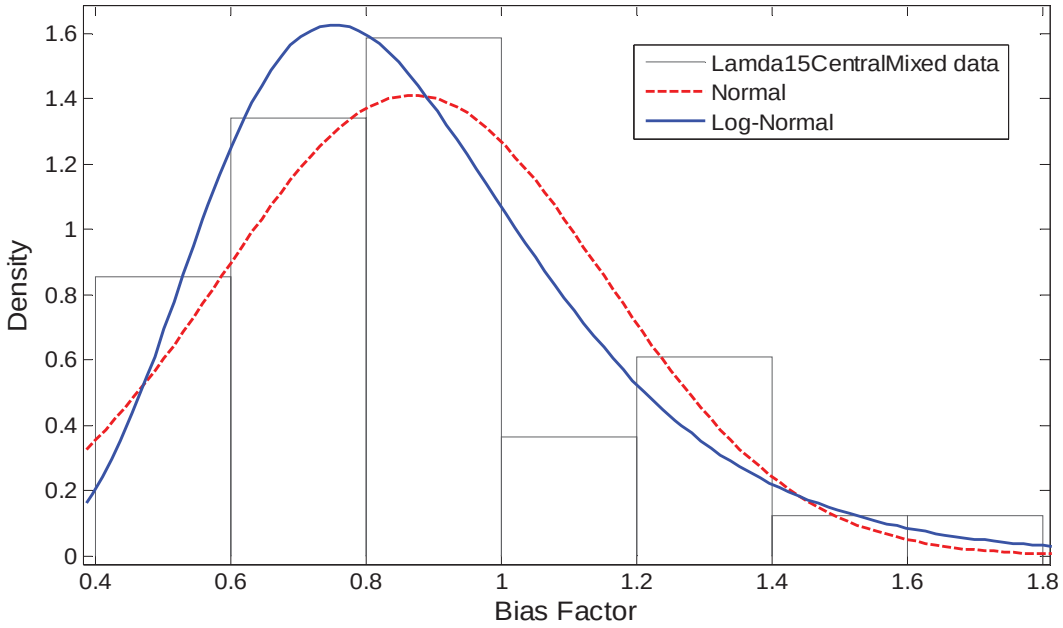


Figure F-M15-eHistogram and frequency distribution of bias factor λ15 for 41cases of concrete piles in Mixed soils using the Schmertmann SPT in Central of Vietnam

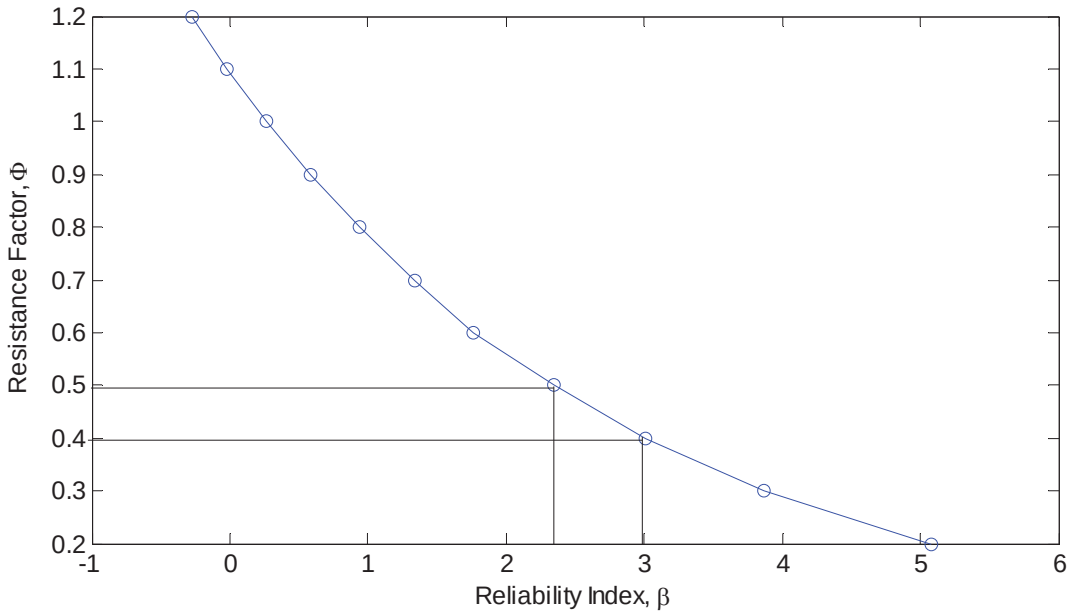


Figure F-M15-fResistance factor calibration for 41cases of concrete piles in Mixed soils using the Schmertmann SPT in Central of Vietnam

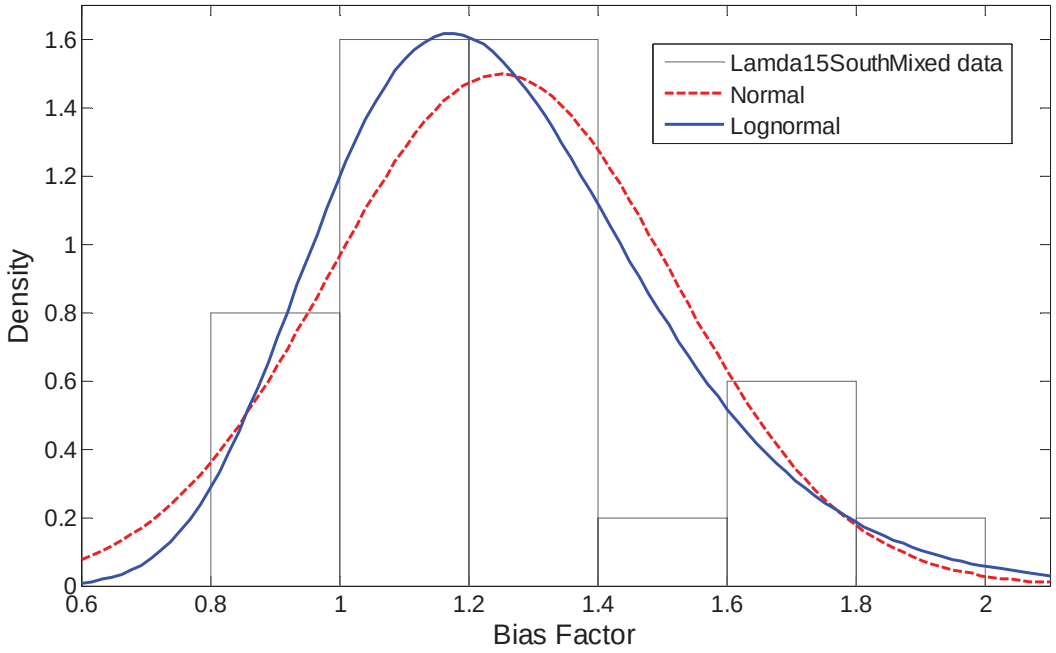


Figure F-M15-gHistogram and frequency distribution of bias factor λ15 for 25cases of concrete piles in Mixed soils using theSchmertmann SPTmethod (ϕ:Schmertmann) in South of Vietnam

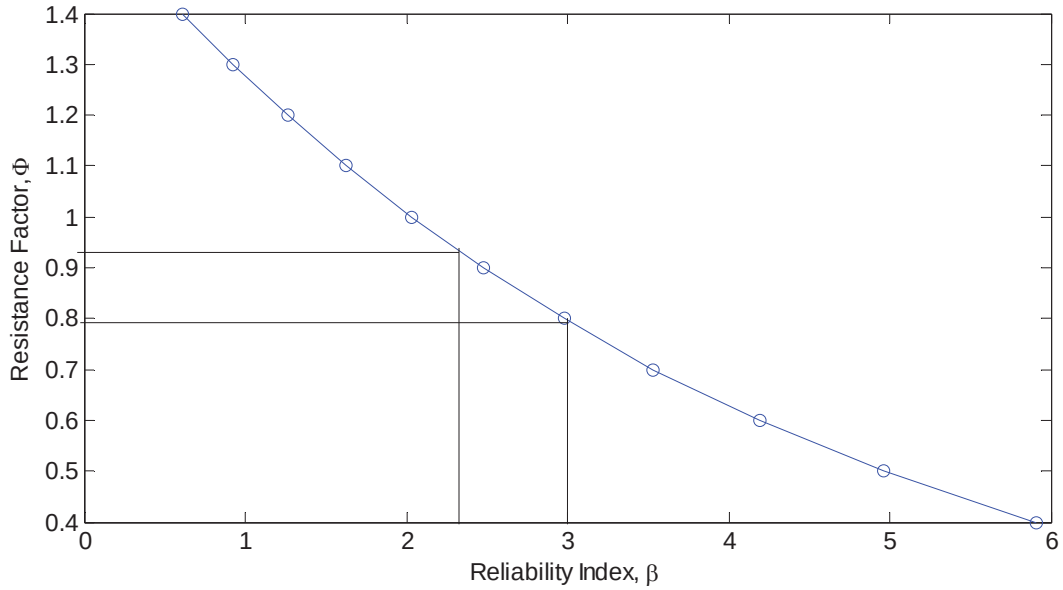


Figure F-M15-hResistance factor calibration for 25 cases of concrete piles in Mixed soils using theSchmertmann SPTmethod (ϕ:Schmertmann) in South of Vietnam

APPENDIX G
Nominal and Measure Capacity of Drilled Shaft from Vietnam

Table G-1 Summary drilled shaft data from Vietnam

No	Name of Project	Location	Soil	Name	(mm)	(m)
NP-M1	181 Nguyen Luong Bang-Hanoi	Hanoi	Mixed	C9	1	47
NP-M2		North Plain		C26	0.8	47
NP-M3	Chung Cu Cao Tang CT4-Van Khe	Hanoi	Mixed	TN-1	1.2	44
NP-M4	HaDong-HaTay	North Plain		TN-2	1.2	44
NP-M5				TN-3	1.2	44
NP-M6	CT1A-CT1B- Xuan La-Tayho-Hanoi	Hanoi	Mixed	TN08	1.2	44
NP-M7		North Plain		TN22	1.0	44
NP-M8				TN26	1.2	44
NP-M9	CT3 Trung Van-Hanoi	Hanoi	Mixed	NT1	1.2	46
NP-M10		North Plain		NT2	1.2	46
NP-M11				NT3	1.0	44
NP-M12				NT4	1.0	45
NP-M13				NT5	0.8	46
NP-M14	11 Tran Hung Dao-Hanoi	Hanoi	Mixed	TN1	1.0	44
NP-M15		North Plain		TN2	0.8	44
NP-M16	235 Nguyen Trai-Hanoi	Hanoi	Mixed	TN1-07	1.0	46
NP-M17		North Plain		TN2-32	1.0	46
NP-M18	Habico-Tower-Hanoi	Hanoi	Mixed	N07	1.2	40
NP-M19		North Plain		N207	1.2	40
NP-M20				N223	1.5	40
NP-M21				N44	1.2	40
NP-M22	Hanoi Central Hotel-44 Ly ThuongKiet St	Hanoi	Mixed	No60	1.0	39
NP-M23	Hanoi Tung Shing Club-151 ThuyKhe-	Hanoi	Mixed	P65	1.2	52
NP-M24	Tay Ho-Hanoi	North Plain		P119	1.2	52
NP-M25				P216	1.2	51
NP-M26				P290	1.0	41
NP-M27	La Khe-Van Khe, Ha Dong-HaTay	Hanoi	Mixed	CN120-14	1.2	49
NP-M28		North Plain	Sand	CN100-03	1.0	49
NP-M29	Logitem Vietnam Corp, No1 project-Thai Thinh	Hanoi	Mixed	C-45	1.0	47
NP-M30	M5 Tower-Nguyen Chi Thanh-Hanoi	Hanoi		TN2-96	1.5	47
NP-M31	NhaKhoSach-Thu VienQuocGia-Hanoi	Hanoi	Mixed	No-2	0.9	46
NP-M32		North Plain		No-3	0.9	45
NP-M33	Nha van phong 149-pho Hue-hanoi	Hanoi	Mixed	TN01-50	0.4	42
NP-M34		North Plain		TN02-123	0.4	43
NP-M35	Thanh Tri Bridge-Hanoi	Hanoi	Mixed	P18	1.5	42
NP-M36		North Plain		P32	1.5	42
NP-M37				P11-L8	1.5	49
NP-M38				P12-R02	1.5	50
NP-M39				P12-R05	1.5	50
NP-M40	Trung Tam Thuong Mai CauGiay-DichVong	Hanoi		No27	1.2	47
NP-M41	CauGiay-Hanoi	North Plain		No92	1.2	44
NP-M42	Trung Tam Thuong Mai-Khu do thi	Hanoi	Mixed	TN07	1.0	37
NP-M43	Nam Thang Long-Tay Ho-Hanoi	North Plain	more	TN16	1.0	37
NP-M44			Sand	TN08	1.0	37
NP-M45				TN04	0.8	37
NP-M46				TN11	1.0	37

Table G-1 (cont.)

NP-M47				TN15	1.0	37
NP-M48				TN03	1.2	37
NP-M49				TN12	1.0	37
NP-M50	Ever Fortune Plaza Hote l- 83 Ly ThuongKiet	Hanoi		D5a	1.0	40
NP-M51	Hanoi Opera Hilton - Hanoi	Hanoi	Mixed	2.00	1.0	38
NP-M52	Phap Van Bridge - Hanoi	Hanoi		P38R32	1.2	44
NP-M53	SaS Royal Hotel-LeNin Park-Hanoi	Hanoi		TP1	1.0	43
NP-M54		North Plain		TP2	0.8	43
NP-M55	Tru So Bo Noi Vu-Khu Do thimoiDichVong	Hanoi	Mixed	TN2	1.0	52
NP-M56	CauGiay-Hanoi	North Plain		TN3	1.0	51
NP-M57				TN4	1.0	51
NP-M58	Trung Tam Thuong Mai Dich Vu	Hanoi		TN1	1.2	50
NP-M59	114 Mai Hac De Hanoi	North Plain		TN2	1.0	50
NP-M60	Indochina Plaza-Hanoi-straingage	Hanoi		TP1	1.0	58
NP-M61		North Plain		TP2	1.5	48
NP-M62				TP3	0.6-2.7	40
NP-M63	My Dinh- TuLiem - Hanoi	Hanoi		N62	1.2	41
NP-M64		North Plain		N100	1.5	42
NP-M65				N207	1.5	42
NP-M66	349 Doi Can-Hanoi	Hanoi		CN2-10	1.2	36
NP-M67		North Plain		CN1-44	1.2	36
NP-M68	114 Mai Hac De -Hanoi	Hanoi		TN1	1.2	49
NP-M69		North Plain		TN2	1.5	49
NP-M70	Ngoc Khanh -Ba Dinh-Hanoi	Hanoi		42.00	1.2	43
NP-M71		North Plain		195.00	0.8	43
NP-M72	B15 - Dai Kim-Dinh Cong-Hanoi	Hanoi		No13	1.0	48
NP-M73		North Plain		No68	1.0	60
NP-M74				No118	1.0	48
NP-M75	335 Duong CauGiay-Hanoi	Hanoi	Mixed	TN01-05	1.0	44
NP-M76		North Plain	more	TN03-54	1.2	44
NP-M77			sand	TN02-36	1.2	44
NP-M78				TN04-94	1.2	44
NP-M79	Thuong Ly Bridge - HaiPhong	Hanoi	Mixed	K35-M3	1.0	59
NP-M80	LachChay Bridge -HaiPhong	HaiPhong	Mixed	No2D	1.0	53
NP-M81	An Duong Bridge - HaiPhong	HaiPhong	Mixed	N16	1.5	51
NP-M82		North Mountain		N06	1.0	48
NP-M83				N07	1.0	46
NP-M84				N10	1.0	42
NP-M85	Truong DH Hung Vuong-Viet Tri-VinhPhu	Viet Tri		TN01	1.2	39
NP-M86		North Mountain		TN06	1.2	34
CP-M1	Cau qua Song han-Danang	Danang		A-8	1.5	37
CP-M2		Central Plain		P-5	2.0	36
SP-M1	Cao Octrung cu PhuThanh-SaiGon	SaiGon		No-73	1.0	32
SP-M2	-	South Plain		No-356	1.0	32
SP-M3	193 dinhthienhoang-PDakao-saigon	SaiGon		TN01	0.8	43
SP-M4		South Plain		TN02	1.0	43
SP-M5	Duong Cao Toc TrungLuong-SaiGon	SaiGon		C5-T27	1.0	54
SP-M6		South Plain		C4-T29	1.0	53

Table G-1 (cont.)

SP-M7				C4-T31	1.0	55
SP-M8				C7-T37	1.0	52
SP-M9				C7-T39	1.0	52
SP-M10				C12-T45	1.0	54
SP-M11				N14-T4	1.5	46
SP-M12	Highrise building Sonadezi-Bien Hoa	SaiGon		CN80-14	0.8	21
SP-M13	Saigon	South Plain		CN80-32	0.8	17
SP-M14				CN100-132	1.0	20
SP-M15				CN100-35	1.0	20
SP-M16	Hung Long comany-SaiGon	SaiGon		CTT06	1.2	60
SP-M17		South Plain		CTT07	1.2	60
SP-M18	Trung Cu UngThanhHao Mon -Phuong 7-Q8	SaiGon		N01-CN2	1.0	60
SP-M19	SaiGon	South Plain		N02-CN1	1.0	60

Table G-2 Summary measure capacity of drilled shaft from North, Central and South of Vietnam by different criterion

No	Design Load (T)	SLT (T)	Measure Capacity				
			Chin's Method	80% Chin's Method	Davision's method	1"	0.5%D
NP-M1	260	520	877	702	783	735	783
NP-M2	260	520	909	727	800	756	800
NP-M3	700	1400	2000	1600	1500	1300	1652
NP-M4	700	1400	2000	1600	1496	1320	1648
NP-M5	700	1400	2000	1600	1680	1520	1730
NP-M6	600	1200	3333	2667	2100	1550	2250
NP-M7	450	900	2000	1600	1700	1540	1780
NP-M8	600	1200					
NP-M9	550	1100	2222	1778	1460	1310	1728
NP-M10	550	1100	2128	1702	1620	1480	1807
NP-M11	370	740	1754	1404	1324	1154	1442
NP-M12	370	740	1370	1096	1121	1045	1186
NP-M13	250	500	1316	1053	1000	950	1098
NP-M14	400	800	1205	964	1010	950	1065
NP-M15	300	600	1042	833	810	720	816
NP-M16	470	940	1429	1143	1250	1160	1279
NP-M17	470	940	1429	1143	1290	1200	1305
NP-M18	883	1766	2941	2353	2200	1900	2390
NP-M19	804	1609	2778	2222	1964	1721	2212
NP-M20	1055	2109	2857	2286	2200	1900	2370
NP-M21	883	1766	2500	2000	1800	1600	2036
NP-M22	300	750	1429	1143	850	800	1014
NP-M23	650	1300	2564	2051	2050	1682	2104
NP-M24	650	937					
NP-M25	650	1031					
NP-M26	400	707					
NP-M27	550	1100	2000	1600	1600	1300	1633
NP-M28	450	900	1887	1509	1500	1250	1508
NP-M29	220	330	526	421	450	460	494

Table G-2 (cont.)

NP-M30	1000	2000	3846	3077	2419	2050	2980
NP-M31	300	450	812	649	685	650	713
NP-M32	300	450	888	710	672	629	722
NP-M33	70	105					
NP-M34	70	105					
NP-M35	501	1002	1754	1404	1510	1462	1645
NP-M36	671	1341	2000	1379	1340	1270	1540
NP-M37	432	864	2439	1951	1937	1748	2186
NP-M38	501	1002	1667	1333	1440	1400	1560
NP-M39	501	1002	2703	2162	2000	1800	2312
NP-M40	570	1140	1887	1509	1577	1470	1653
NP-M41	570	1140	1887	1509	1470	1380	1594
NP-M42	450	900	1429	1143	1185	1082	1232
NP-M43	450	900	1429	1143	1167	1072	1225
NP-M44	450	900	1429	1143	1150	1050	1210
NP-M45	300	600	1429	1143	1200	1100	1250
NP-M46	450	900	1429	1143	1163	1068	1222
NP-M47	450	900	1429	1143	1237	1162	1282
NP-M48	600	1200	1111	889	951	910	1000
NP-M49	450	900	1429	1143	1100	1000	1185
NP-M50	435	870	1808	1447	1195	1025	1308
NP-M51		960	1890	1512	1300	1095	1387
NP-M52		790	1460	1168	1113	1043	1250
NP-M53		770	1235	988	975	900	1042
NP-M54		370	575	460	460	450	493
NP-M55	550	1100	1701	1361	1512	1348	1504
NP-M56	550	1100	1745	1396	1512	1330	1509
NP-M57	550	1100	1582	1266	1375	1195	1361
NP-M58	750	1300	2083	1667	1626	1474	1777
NP-M59	400	800	1370	1096	1100	1069	1201
NP-M60	-	2400	5556	4444	4000	2100	3000
NP-M61	-	2400	5263	4211	4025	3209	4000
NP-M62	-	2600	3704	2963	2844	2436	3000
NP-M63			3333	2667	2206	1850	2350
NP-M64			4167	3333	2933	2500	3402
NP-M65			4000	3200	2750	2340	3234
NP-M66	750	1500	2439	1951	1826	1600	2000
NP-M67	750	1500	2326	1860	1900	1734	2036
NP-M68	1100	2200	3333	2667	2400	1850	2455
NP-M69	1550	3100	5263	4211	2712	1935	3400
NP-M70	620	1240	2703	2162	1569	1700	2178
NP-M71	270	540	1163	930	848	800	900
NP-M72	440	880	1961	1569	1367	1125	1400
NP-M73	440	880	2222	1778	1743	1590	1600
NP-M74	440	880	1887	1509	1400	1100	1400
NP-M75	450	1000	1408	1127	1200	1125	1257
NP-M76	600	1200	1724	1379	1472	1400	1553
NP-M77	600	1200	1754	1404	1485	1415	1567

Table G-2 (cont.)

NP-M78	600	1200	1754	1404	1500	1425	1601
NP-M79		460	1114	891	890	789	924
NP-M80		450	870	696	710	750	786
NP-M81		1314	2083	1667	1750	1550	1869
NP-M82		527	1235	988	844	775	927
NP-M83		527	1149	920	900	821	958
NP-M84		527	1064	851	894	840	939
NP-M85	600	1200	2000	1600	1668	1534	1775
NP-M86	600	1200	1429	1143	1266	1238	1342
CP-M1	1500	3000	4000	3200	2500	2000	3070
CP-M2	1800	3600	5000	4000	3200	2750	4163
SP-M1	400	657					
SP-M2	400	600					
SP-M3	320	640	1111	889	879	769	909
SP-M4	450	900	1250	1000	1075	1072	1114
SP-M5		664					
SP-M6		671					
SP-M7		598					
SP-M8		625					
SP-M9		670					
SP-M10		682					
SP-M11	500	750	1000	800	900	900	965
SP-M12	270	540	1000	800	590	654	752
SP-M13	270	540	588	471	300	405	500
SP-M14	450	900	667	533	350	654	540
SP-M15	450	900	833	667	480	530	659
SP-M16	620	1240	1429	1143	1178	1150	1307
SP-M17	620	1426	2500	2000	1360	1200	1426
SP-M18	520	1040					
SP-M19	520	1040					

Table G-3 Summary Nominal Capacity of Drilled Shaft from North, Central and South of Vietnam by Different Method

	FHWA method		Reese and Wright method	
No	Su:Terzaghi, Peck	Su: (Hara)	Su: Terzaghi, Peck	Su: Hara
NP-M1 NP-M2	543.80	621.16	585.41	662.77
NP-M3 NP-M4 NP-M5	1238.87	1385.92	1309.79	1456.84
NP-M6 NP-M7 NP-M8	1134.73	1213.33	1686.40	1764.99
NP-M9	1134.78	1367.76	1230.41	1463.39

Table G-3 (cont.)

NP-M10				
NP-M11	843.77	922.89	905.24	740.67
NP-M12				
NP-M13	637.30	700.59	677.37	740.67
NP-M14	932.11	1180.96	893.64	1142.49
NP-M15	714.02	913.10	682.34	881.42
NP-M16	772.73	1203.86	802.19	1233.32
NP-M17				
NP-M18	1233.76	1729.47	1653.25	2148.96
NP-M19				
NP-M20				
NP-M21				
NP-M22	696.56	939.73	1034.85	1278.02
NP-M23	1326.33	1484.64	1963.45	2121.76
NP-M24				
NP-M25				
NP-M26				
NP-M27	1170.21	1452.24	1646.93	1928.96
NP-M28	934.61	1131.77	1309.66	1506.82
NP-M29	451.34	638.94	403.02	590.62
NP-M30	1182.18	1885.85	1583.55	1885.85
NP-M31	762.25	852.31	938.33	1028.39
NP-M32				
NP-M33	286.36	424.45	389.60	527.68
NP-M34				
NP-M35	1411.24	1581.35	1648.57	1818.68
NP-M36	1365.70	1534.11	1716.45	1884.86
NP-M37	1707.37	1976.96	1939.74	2209.33
NP-M38	1633.16	1633.16	2030.55	2030.55
NP-M39	1846.02	1846.02	2254.86	2254.86
NP-M40	890.48	1211.41	1600.64	1921.57
NP-M41				
NP-M42	851.67	879.16	1229.80	1257.28
NP-M43				
NP-M44				
NP-M45				
NP-M46				
NP-M47				
NP-M48				
NP-M49				
NP-M50	848.80	1019.96	1166.91	1338.08
NP-M51	820.41	960.99	892.52	1033.10
NP-M52	925.13	1070.41	824.72	970.00
NP-M53	729.72	993.55	814.54	1078.37
NP-M54	479.69	519.07	544.19	583.57

Table G-3 (cont.)

NP-M55	1224.00	1369.03	1688.12	1833.15
NP-M56				
NP-M57				
NP-M58	1363.62	1607.99	1688.94	1933.31
NP-M59	1363.62	1607.99	1688.94	1933.31
NP-M60	1268.64	1515.86	1891.32	2138.53
NP-M61	1444.37	1838.09	2292.32	2686.05
NP-M62	1727.57	2372.46	2805.57	3450.46
NP-M63	1067.81	1379.71	1705.95	2017.84
NP-M64	1508.51	1898.37	2377.11	2766.98
NP-M65	1508.51	1898.37	2377.11	2766.98
NP-M66	901.00	1087.13	1396.01	1582.14
NP-M67	913.79	1115.55	1406.53	1608.29
NP-M68	1152.42	1659.95	1326.40	1833.93
NP-M69	1570.47	2204.88	1819.81	2454.22
NP-M70	909.83	1045.71	1556.54	1692.42
NP-M71	536.78	625.61	960.14	1048.97
NP-M72	670.08	1041.75	830.22	1201.89
NP-M73	756.41	1082.73	858.07	1184.39
NP-M74	661.24	1058.87	799.55	1197.18
NP-M75	776.73	1036.98	995.23	1255.49
NP-M76	991.05	1303.36	1303.86	1616.17
NP-M77				
NP-M78				
NP-M79	822.60	1542.78	978.04	1698.22
NP-M80	749.81	1210.36	994.93	1455.47
NP-M81	1132.07	1536.67	1749.77	2154.37
NP-M82	611.91	881.65	730.46	1000.20
NP-M83				
NP-M84				
NP-M85	1473.42	2451.94	1652.22	2630.74
NP-M86	1253.21	2134.29	1338.21	2219.29
CP-M1	1225.45	1923.29	1582.55	2280.39
CP-M2	1419.35	2254.86	2220.06	3055.57
SP-M1				
SP-M2				
SP-M3	740.61	813.98	655.61	728.97
SP-M4	970.74	1089.37	864.49	983.12
SP-M5				
SP-M6				
SP-M7				
SP-M8				
SP-M9				
SP-M10				
SP-M11	995	1778	995	1778

Table G-3 (cont.)

SP-M12	397.84	616.12	701.19	919.46
SP-M13 SP-M14 SP-M15	612.73	922.14	970.95	1280.35
SP-M16 SP-M17	1291.36	1620.90	1571.04	1900.58

APPENDIX H
Histogram and Frequency Distribution of Bias Factor for Drilled Shaft

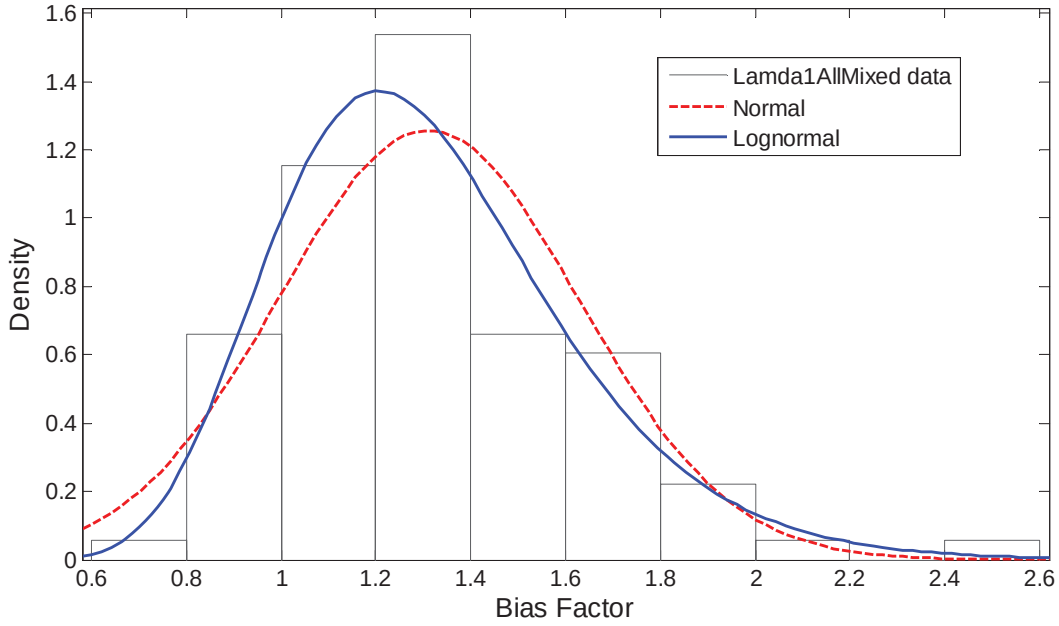


Figure H-M1-a. Histogram and frequency distribution of bias factor λ1 for 92 cases of drilled shaft in Mixed soils using the FHWA method (Su: Terzaghi, Peck) and using 1" criterion in Vietnam

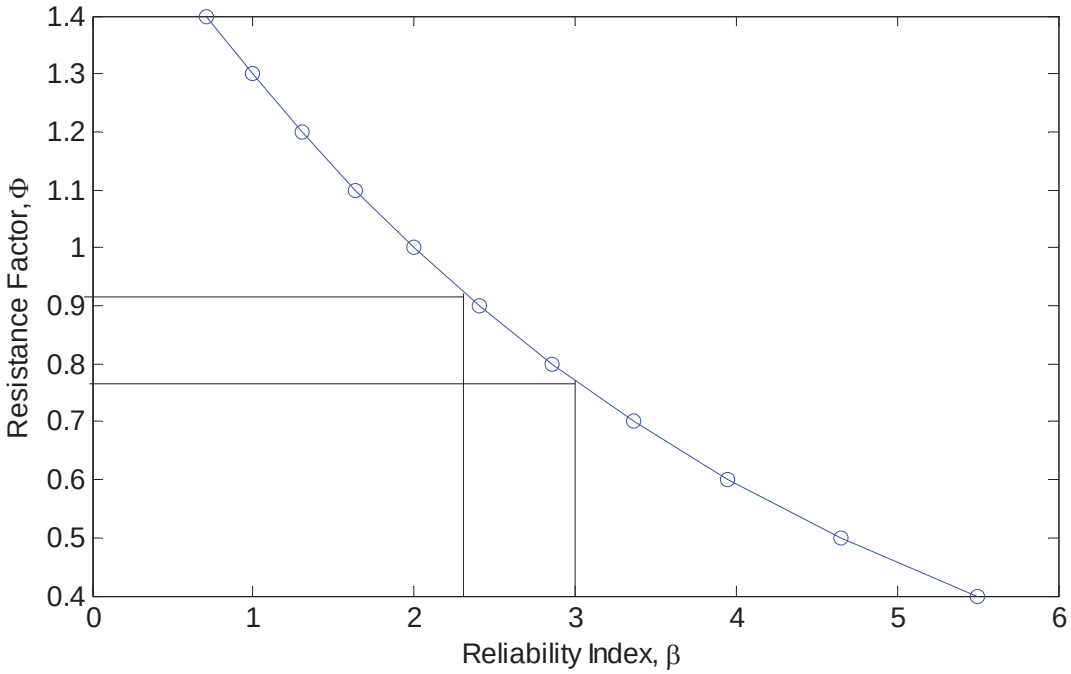


Figure H-M1-b.Resistance factor calibration for 92 cases of drilled shaft in Mixed soils using the FHWA method (Su: Terzaghi, Peck) and using 1" criterion in Vietnam

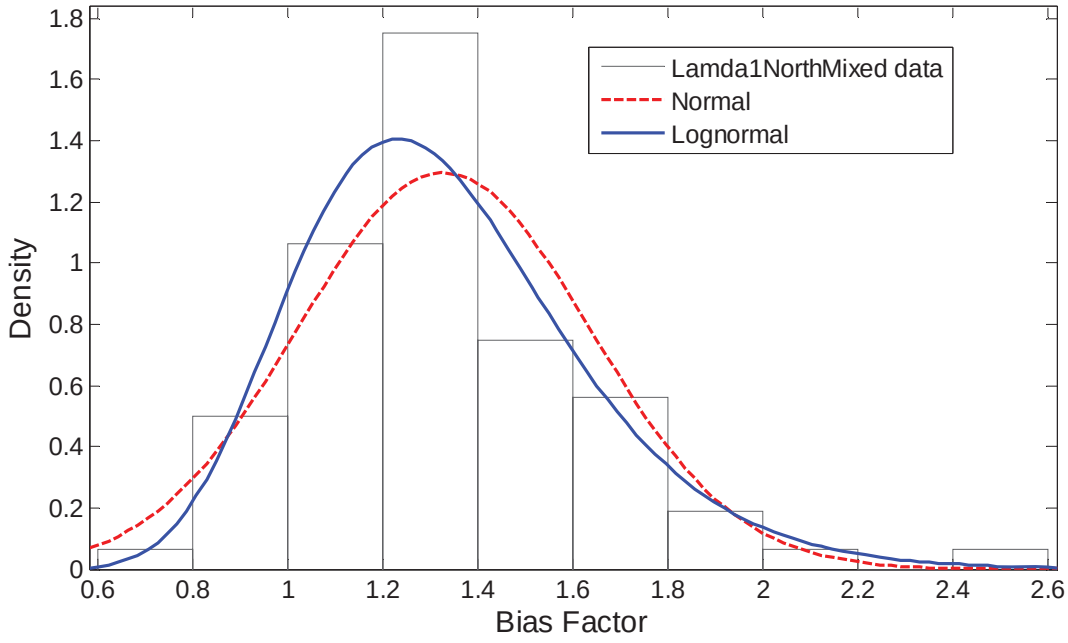


Figure H-M1-c. Histogram and frequency distribution of bias factor λ1 for 80 cases of drilled shaft in Mixed soils using the FHWA method (Su: Terzaghi, Peck) and using 1" criterion in North of Vietnam

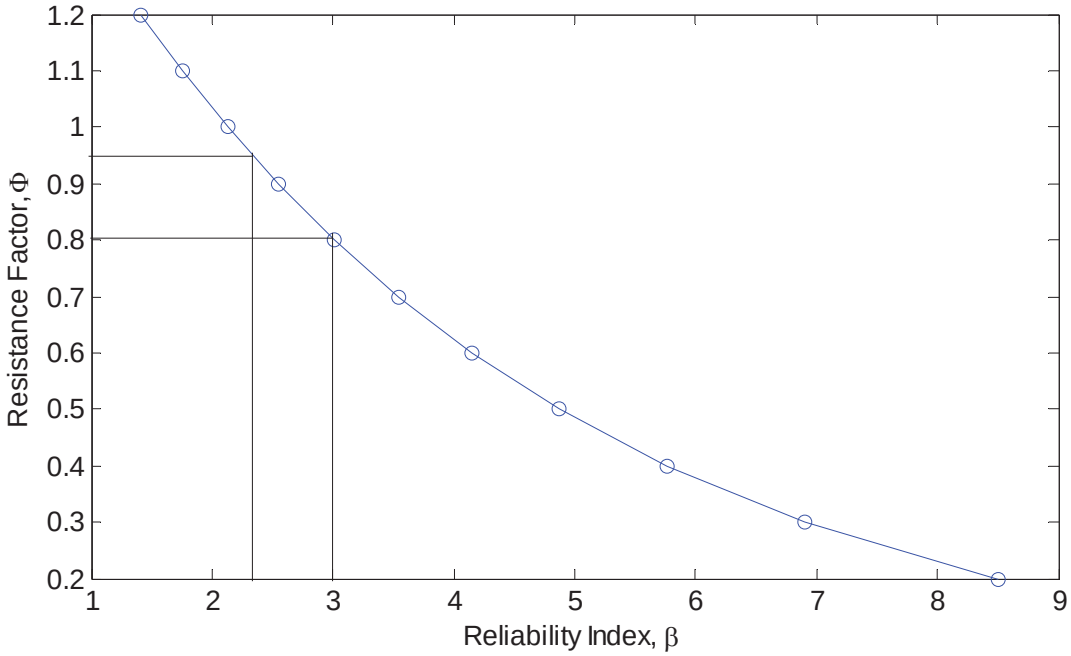


Figure H-M1-d. Resistance factor calibration for 80 cases of drilled shaft in Mixed soils using the FHWA method (Su: Terzaghi, Peck) and using 1" criterion in North of Vietnam

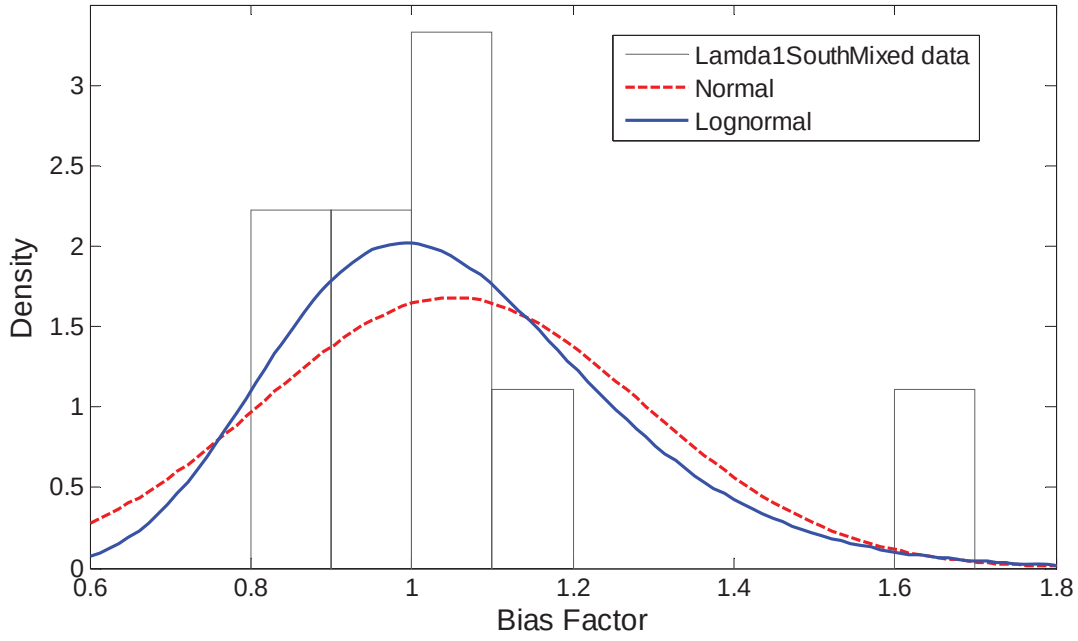


Figure H-M1-e. Histogram and frequency distribution of bias factor λ1 for 10 cases of drilled shaft in Mixed soils using the FHWA method (Su: Terzaghi, Peck) and using 1" criterion in South of Vietnam

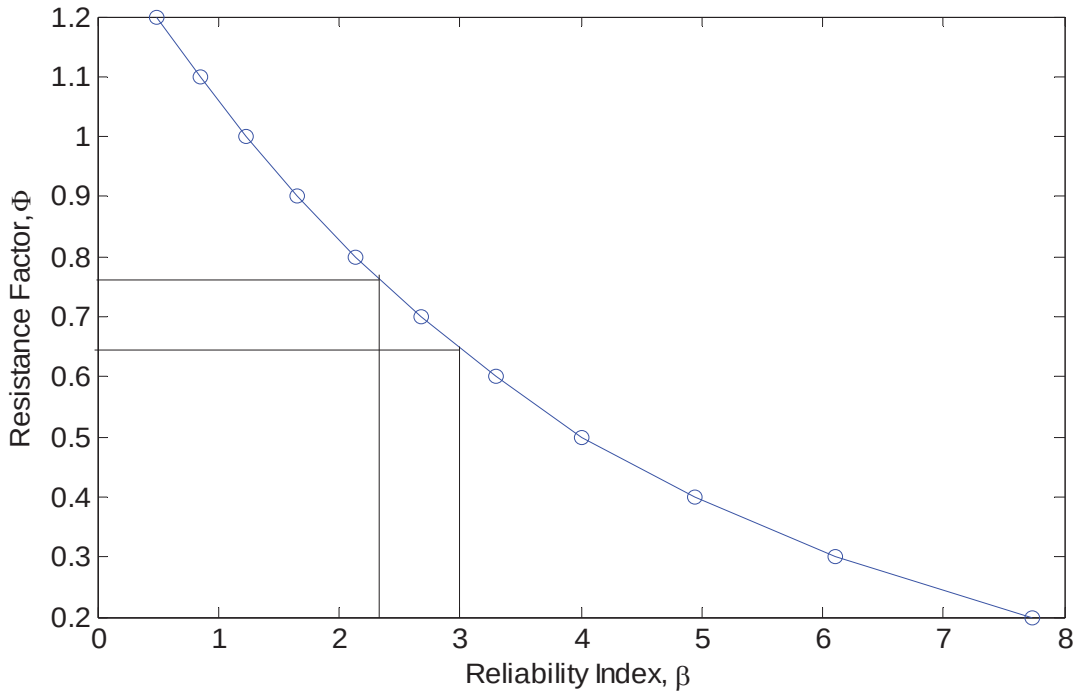


Figure H-M1-f. Resistance factor calibration for 10 cases of drilled shaft in Mixed soils using the FHWA method (Su: Terzaghi, Peck) and using 1" criterion in South of Vietnam

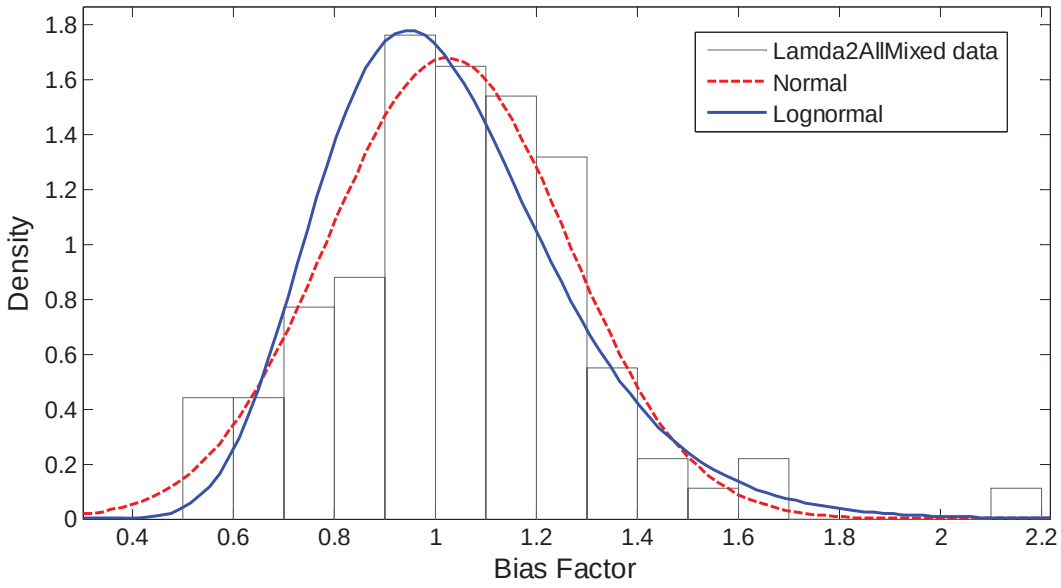


Figure H-M2-a. Histogram and frequency distribution of bias factor λ2 for 92 cases of drilled shaft in Mixed soils using the FHWA method (Su: Hara) and using 1" criterion in Vietnam

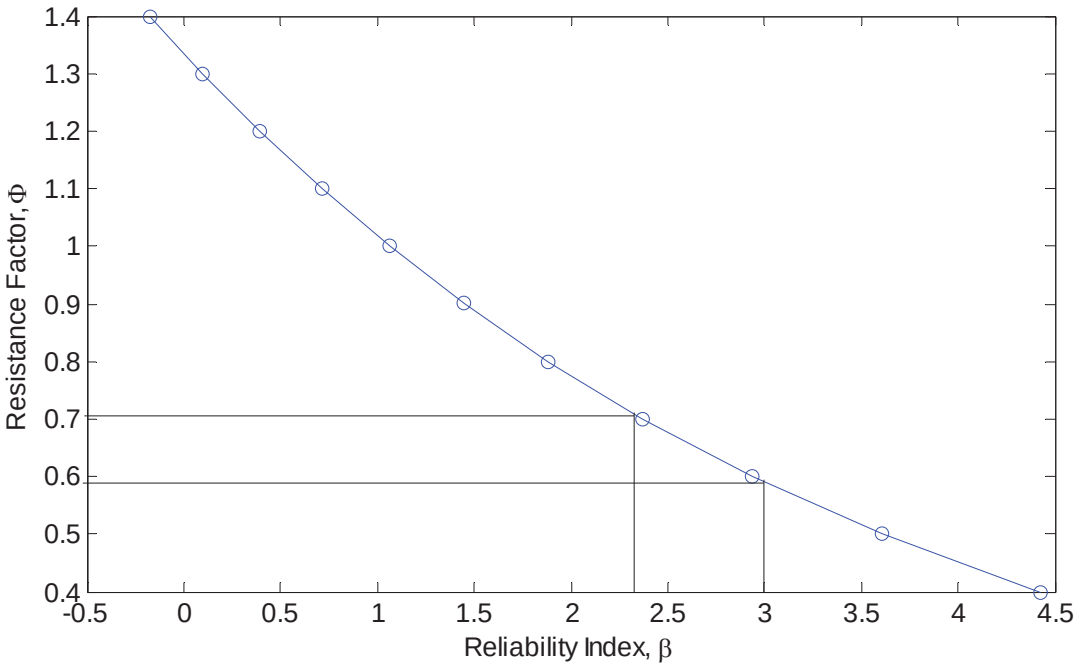


Figure H-M2-b. Resistance factor calibration for 92 cases of drilled shaft in Mixed soils using the FHWA method (Su: Hara) and using 1" criterion in Vietnam

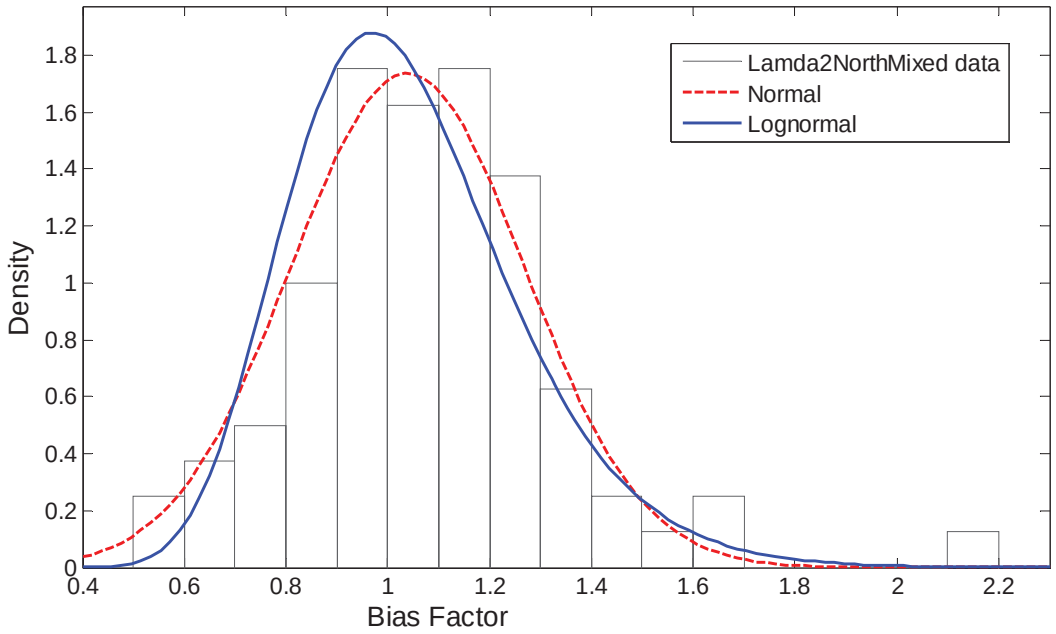


Figure H-M2-c. Histogram and frequency distribution of bias factor λ2 for 80 cases of drilled shaft in Mixed soils using the FHWA method (Su: Hara) and using 1" criterion in North of Vietnam

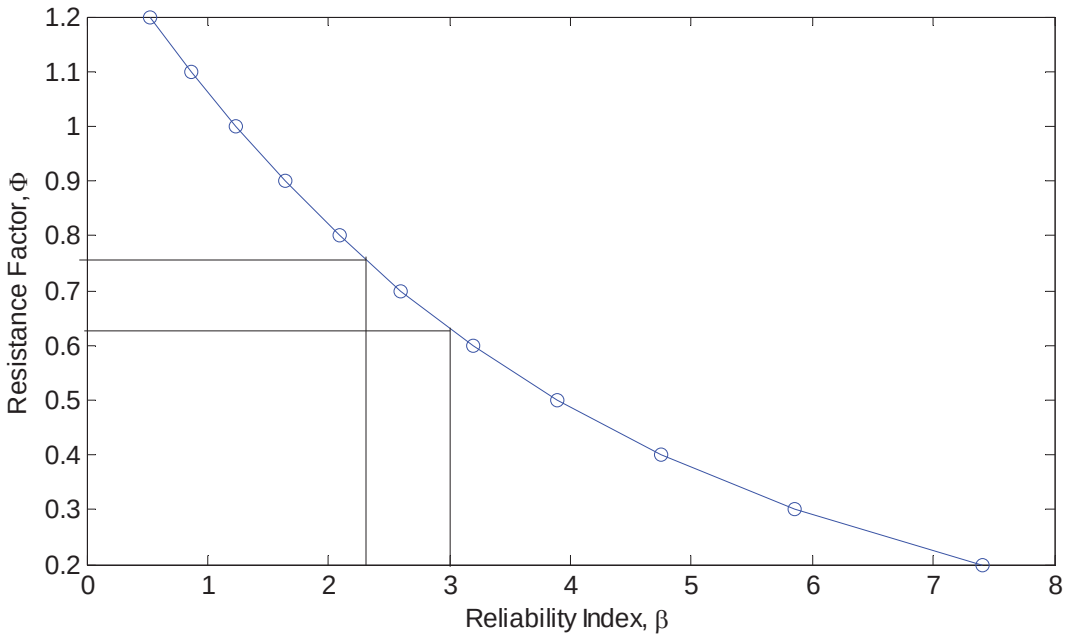


Figure H-M2-d. Resistance factor calibrationfor 80 cases of drilled shaft in Mixed soils using the FHWA method (Su: Hara) and using 1" criterion in North of Vietnam

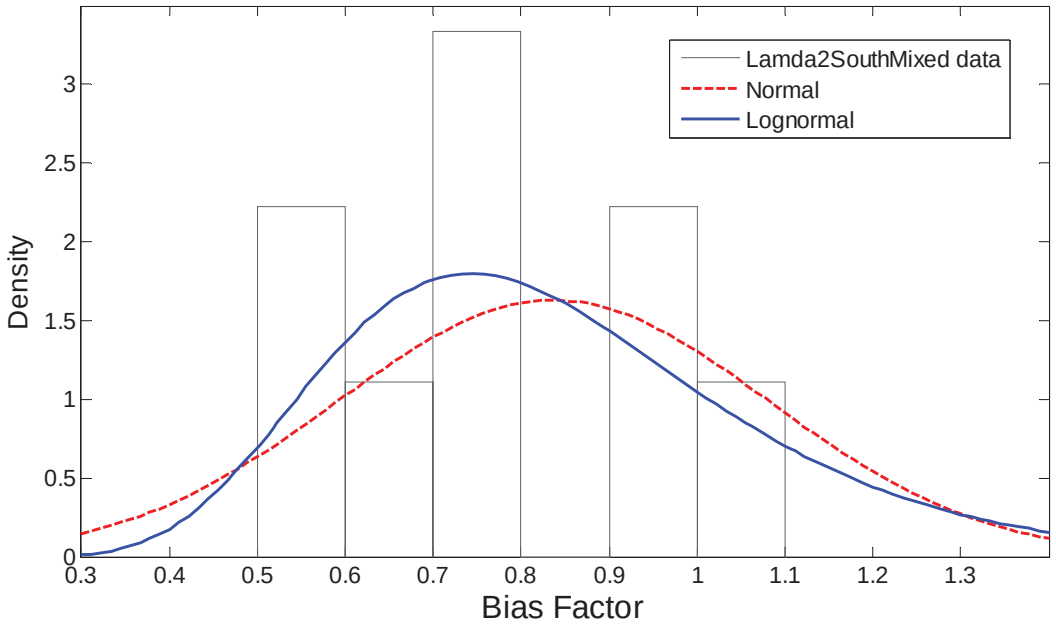


Figure H-M2-e. Histogram and frequency distribution of bias factor λ2 for 10 cases of drilled shaft in Mixed soils using the FHWA method (Su:Hara) and using 1" criterion in South of Vietnam

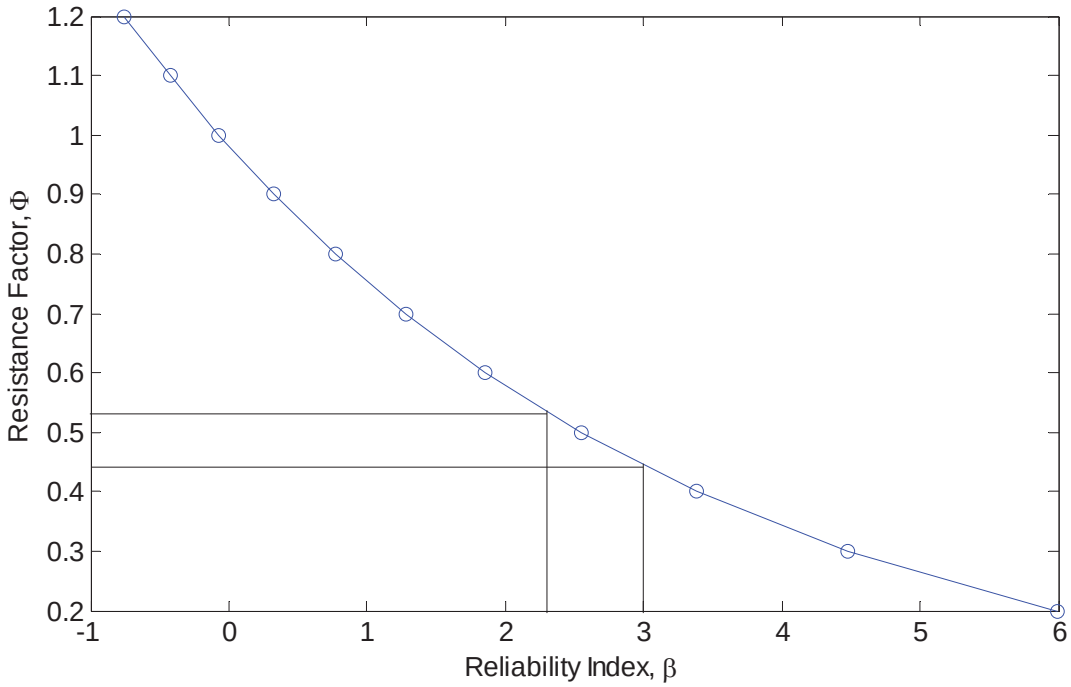


Figure H-M2-f. Resistance factor calibrationfor 10 cases of drilled shaft in Mixed soils using the FHWA method (Su:Hara) and using 1" criterion in South of Vietnam

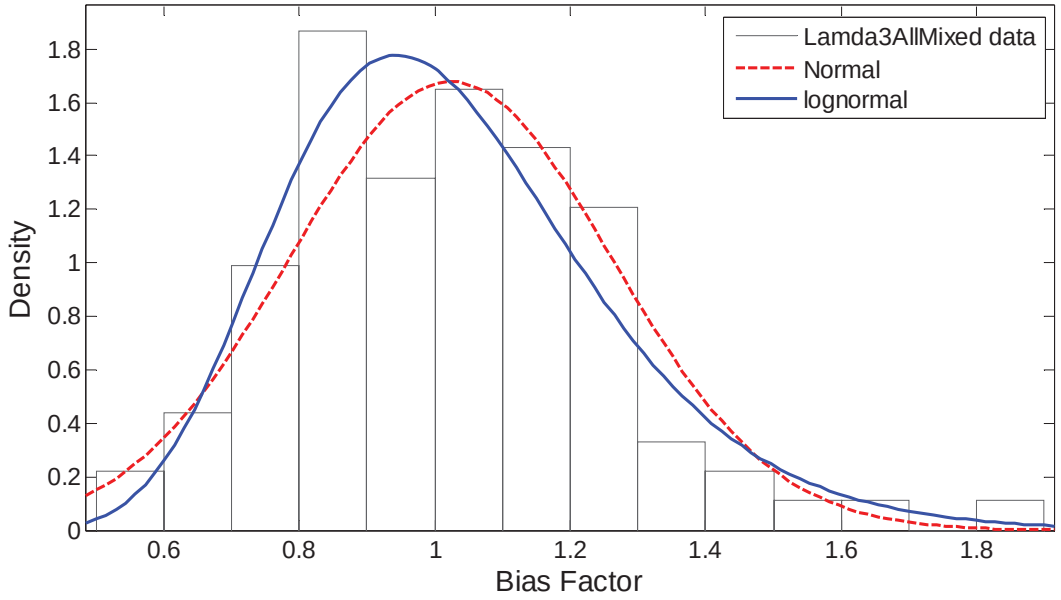


Figure H-M3-a. Histogram and frequency distribution of bias factor λ3 for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 1" criterion in Vietnam

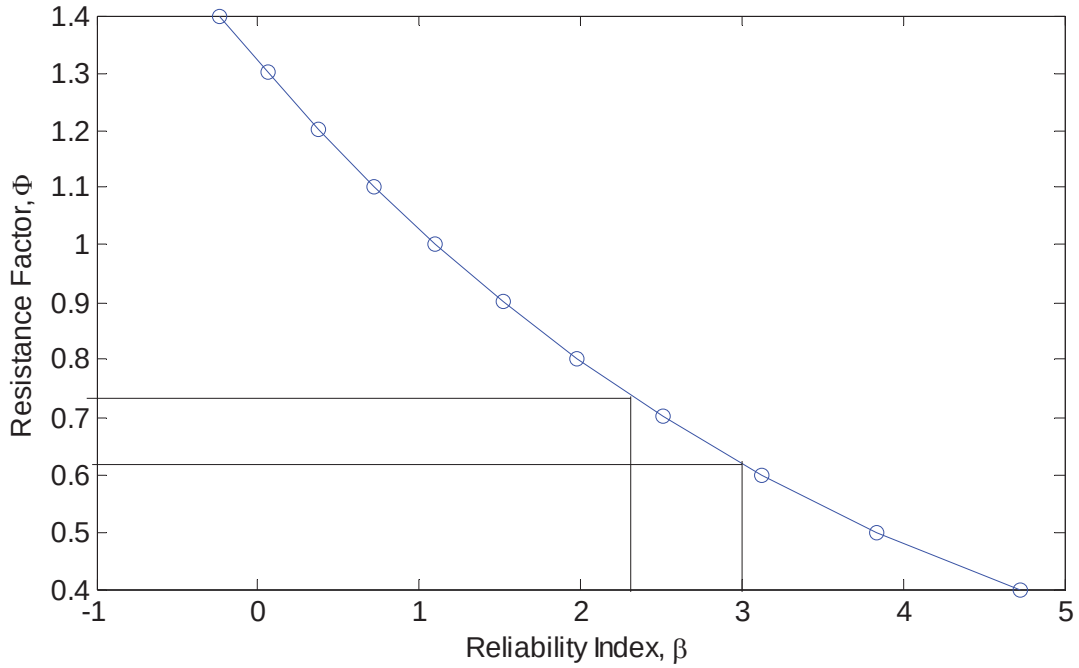


Figure H-M3-b. Resistance factor calibration for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 1" criterion in Vietnam

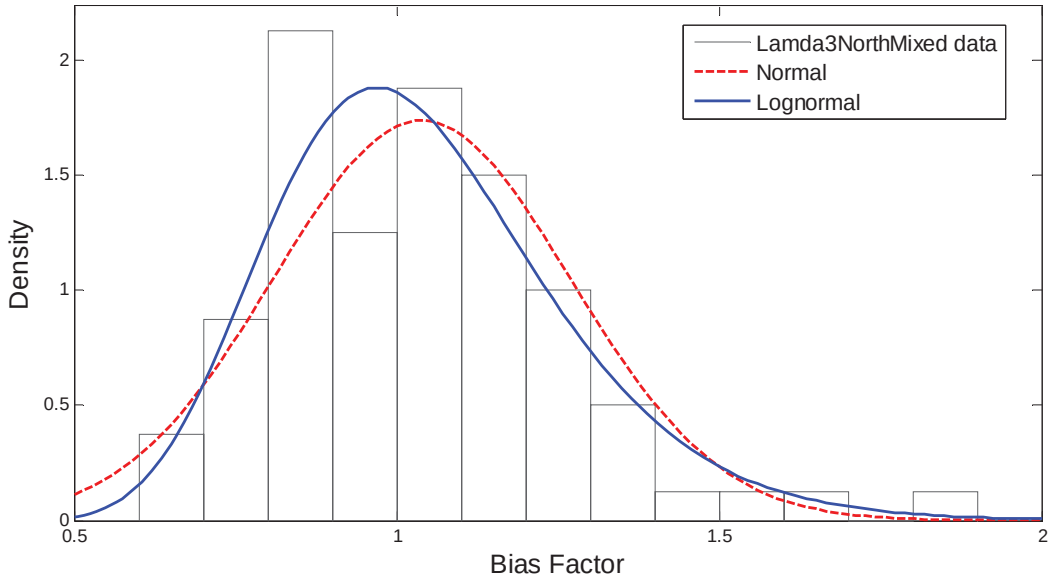


Figure H-M3-c. Histogram and frequency distribution of bias factor λ3 for 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 1" criterion in North of Vietnam

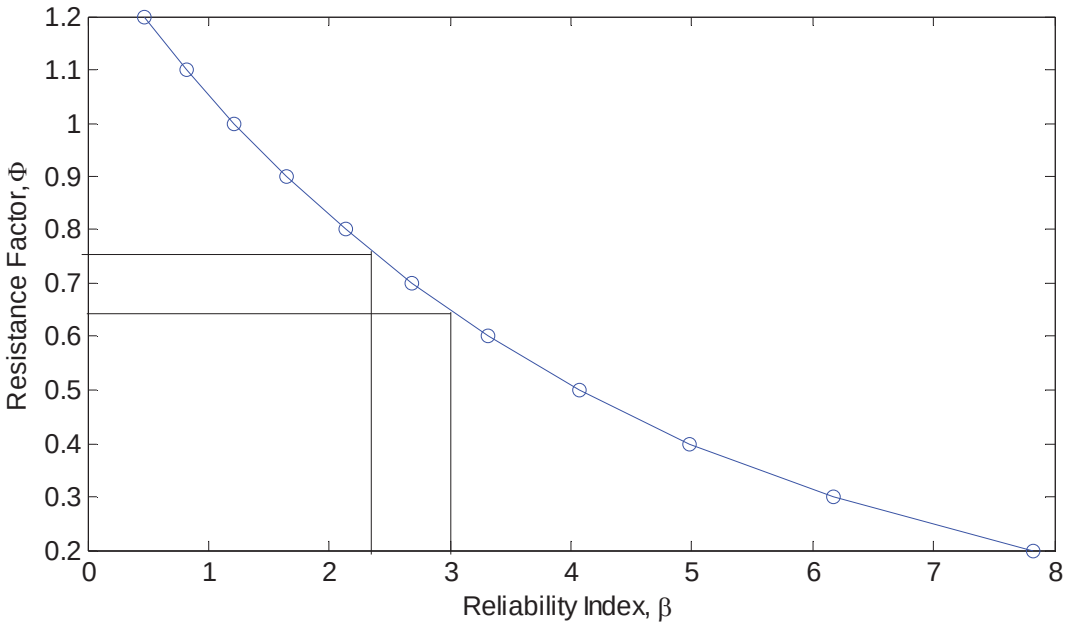


Figure H-M3-d. Resistance factor calibration for 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 1" criterion in North of Vietnam

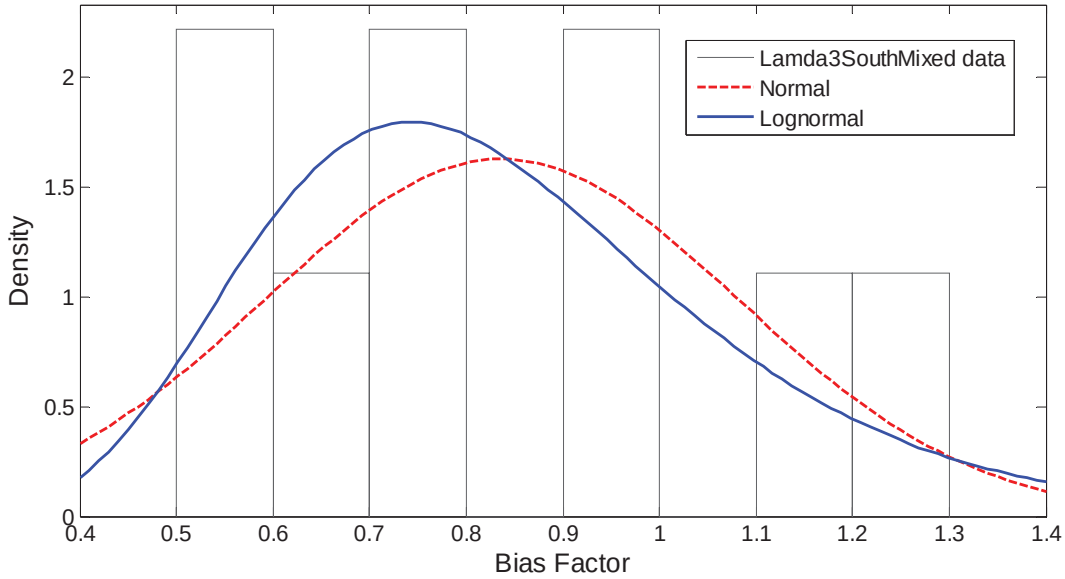


Figure H-M3-e. Histogram and frequency distribution of bias factor λ3 for 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su:Tezaghi, Peck) and using 1" criterion in South of Vietnam

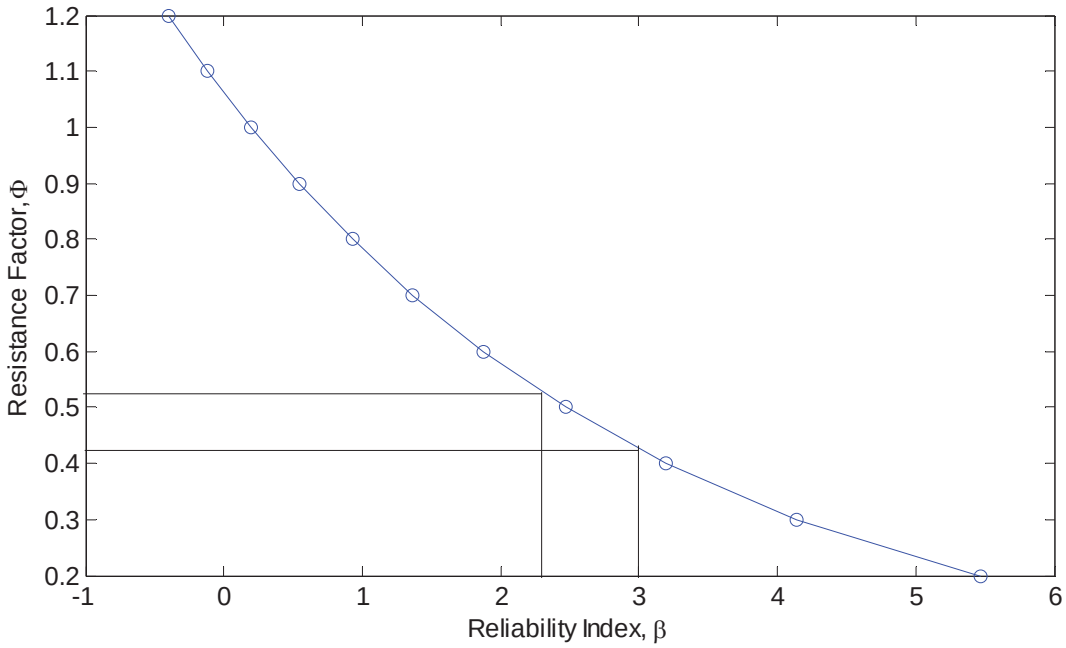


Figure H-M3-f. Resistance factor calibrationfor 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su:Tezaghi, Peck) and using 1" criterion in South of Vietnam

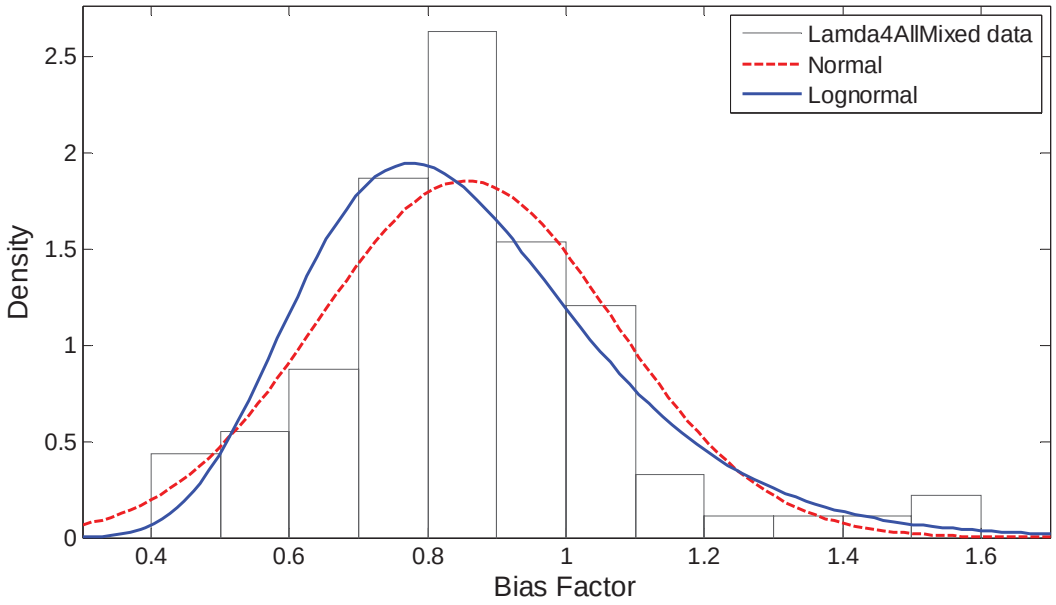


Figure H-M4-a. Histogram and frequency distribution of bias factor λ4 for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 1" criterion in Vietnam

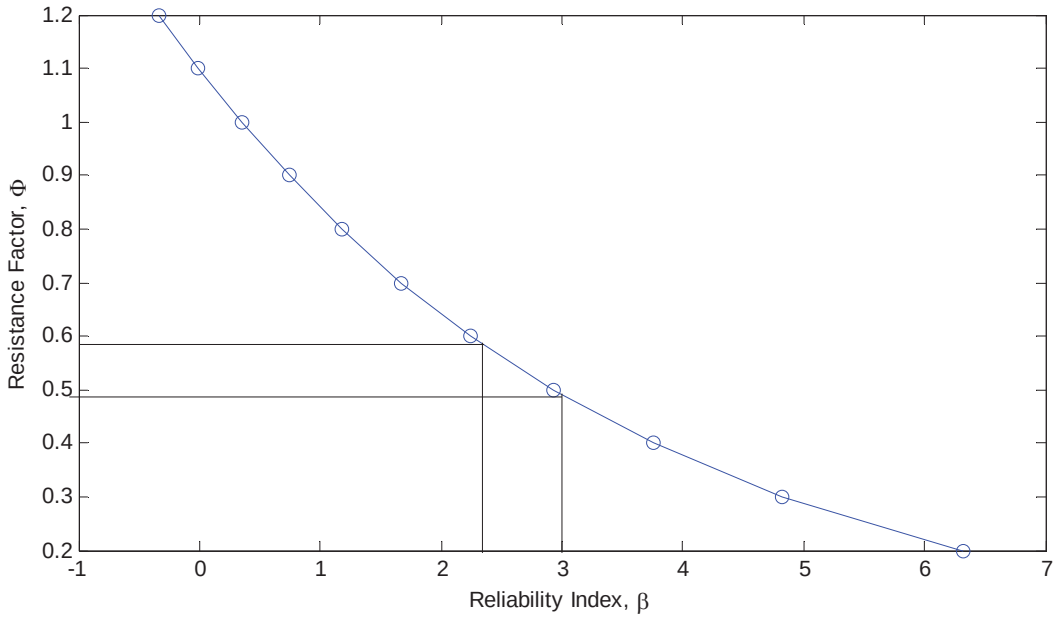


Figure H-M4-b. Resistance factor calibration for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 1" criterion in Vietnam

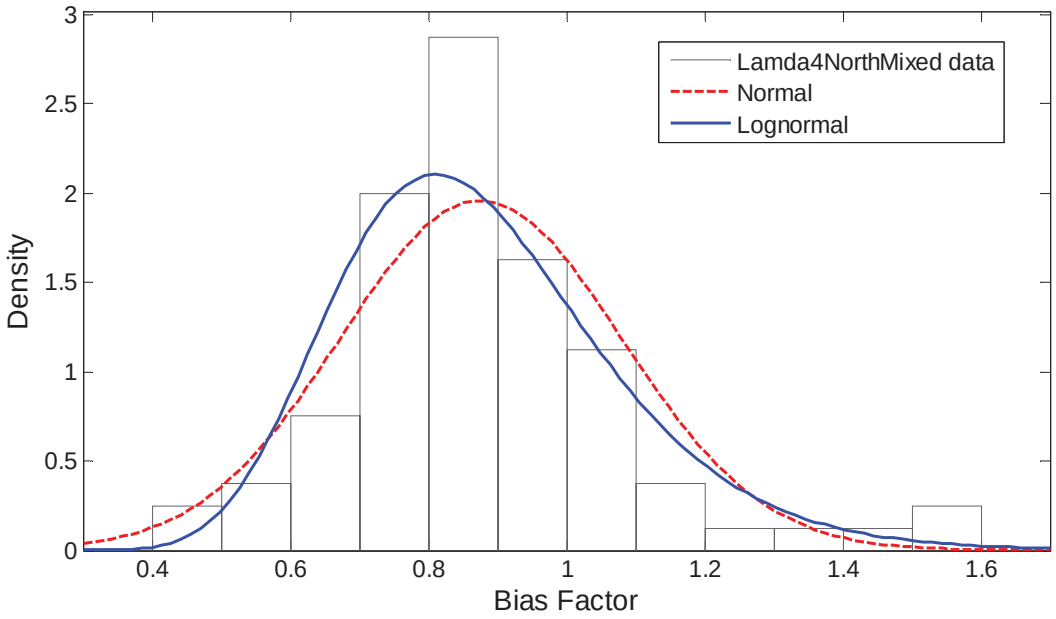


Figure H-M4-c. Histogram and frequency distribution of bias factor λ4 for 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 1" criterion in North of Vietnam

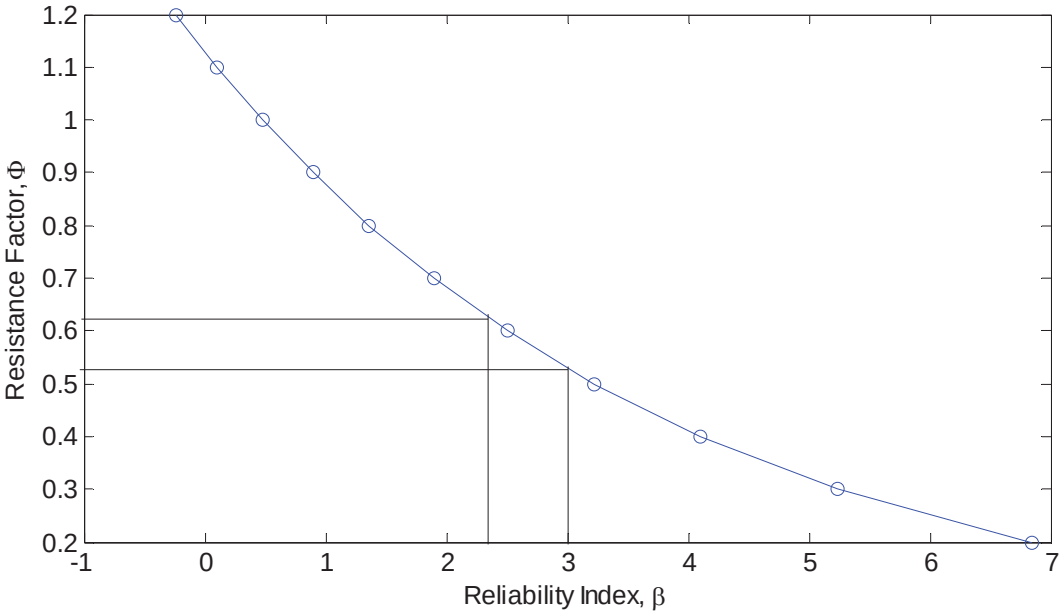


Figure H-M4-d. Resistance factor calibrationfor 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 1" criterion in North of Vietnam

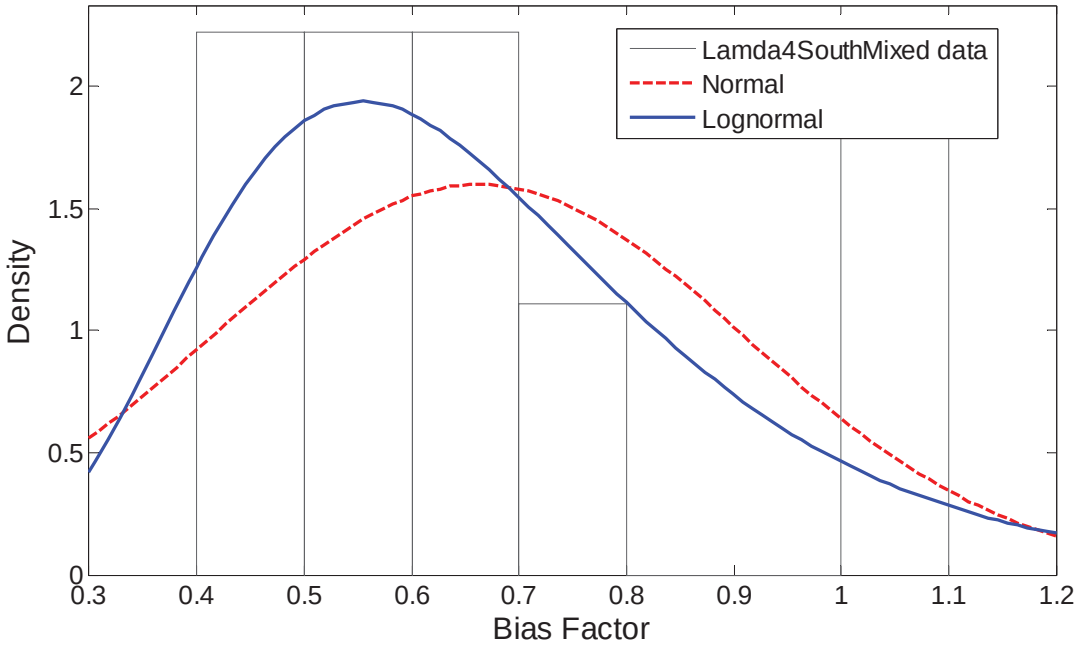


Figure H-M4-e. Histogram and frequency distribution of bias factor λ4 for 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 1" criterion in South of Vietnam

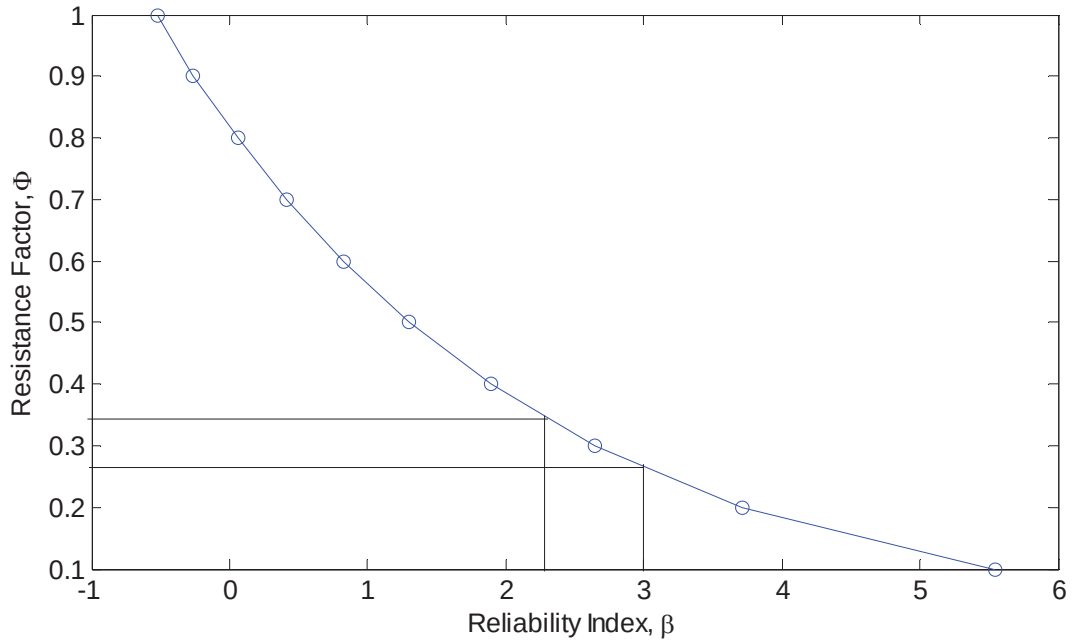


Figure H-M4-f. Resistance factor calibrationfor 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 1" criterion in South of Vietnam

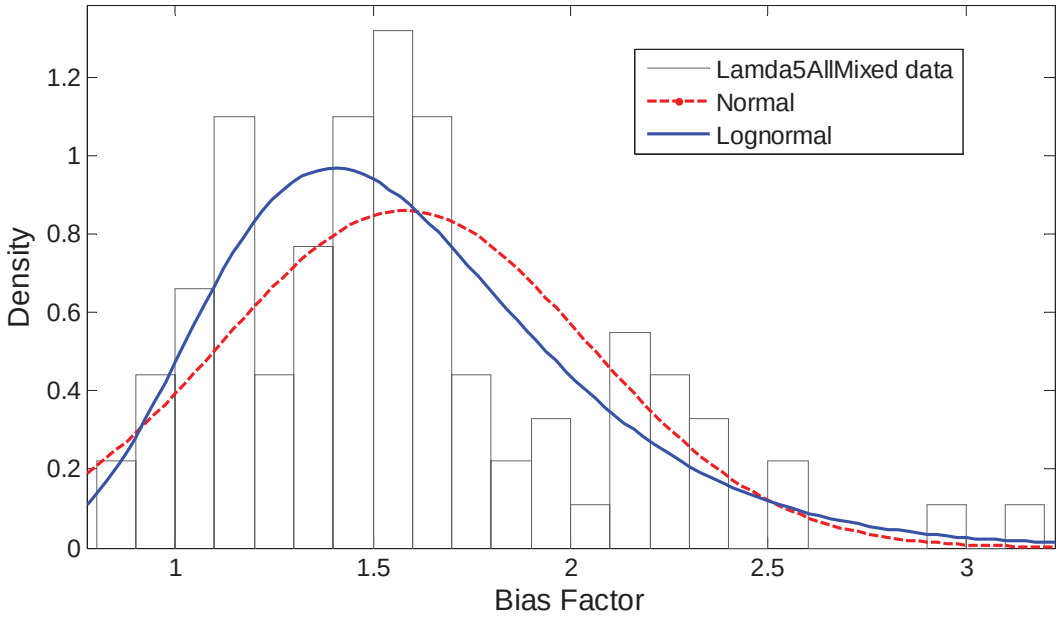


Figure H-M5-a. Histogram and frequency distribution of bias factor λ5 for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in Vietnam

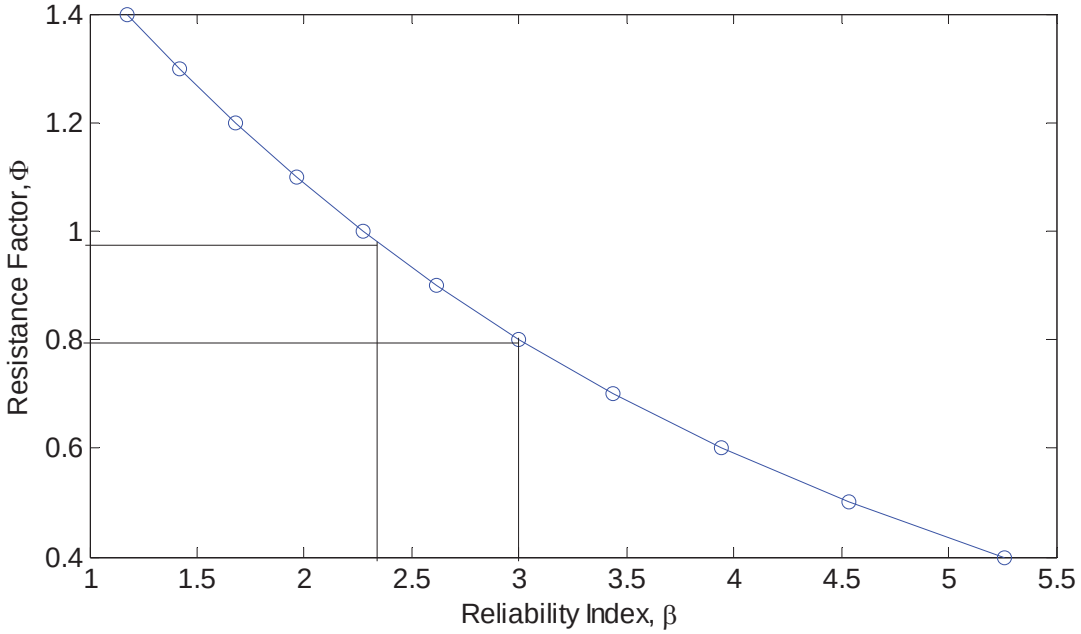


Figure H-M5-b. Resistance factor calibrationfor 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in Vietnam

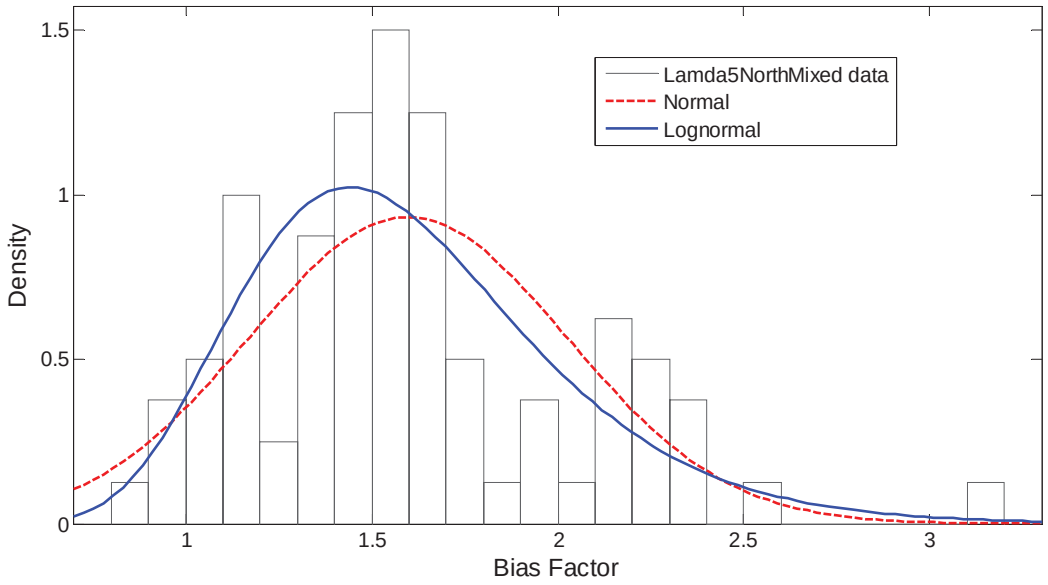


Figure H-M5-c. Histogram and frequency distribution of bias factor λ5 for 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in North of Vietnam

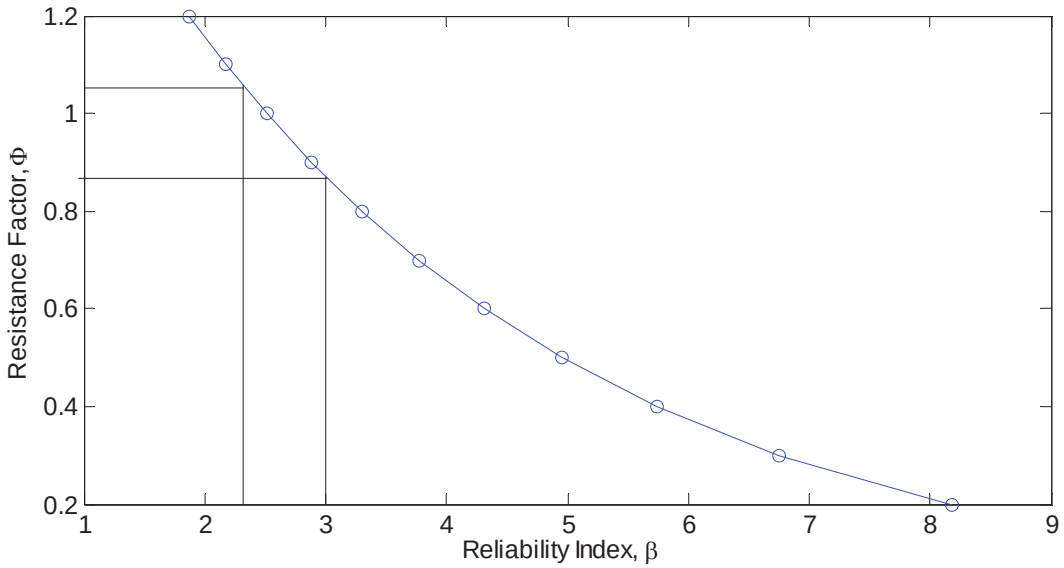


Figure H-M5-d. Resistance factor calibrationfor 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in North of Vietnam

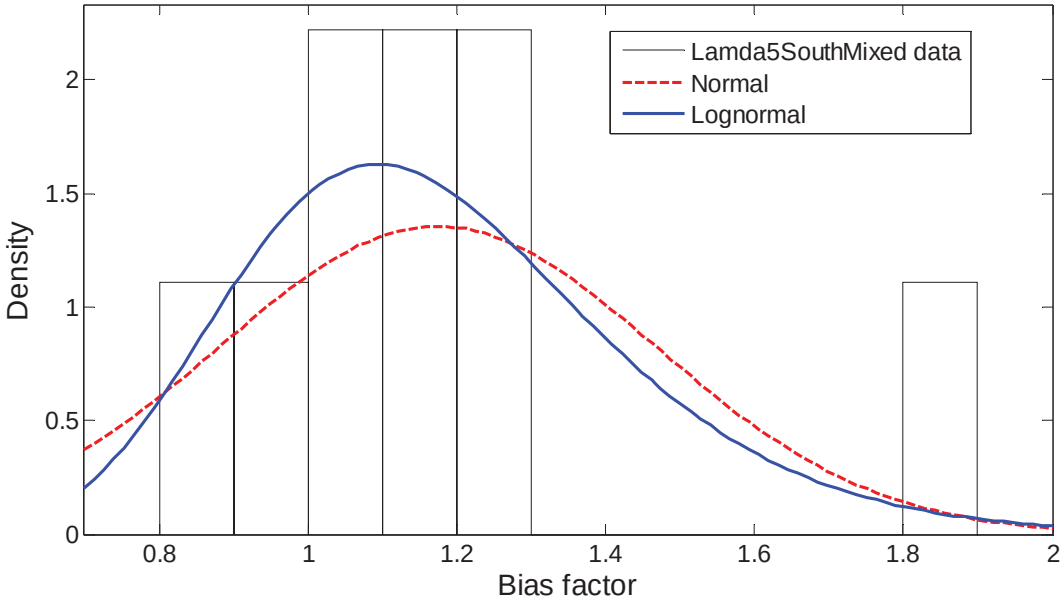


Figure H-M5-e. Histogram and frequency distribution of bias factor λ5 for 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su:Tezaghi, Peck) and using 0.5% D criterion in South of Vietnam

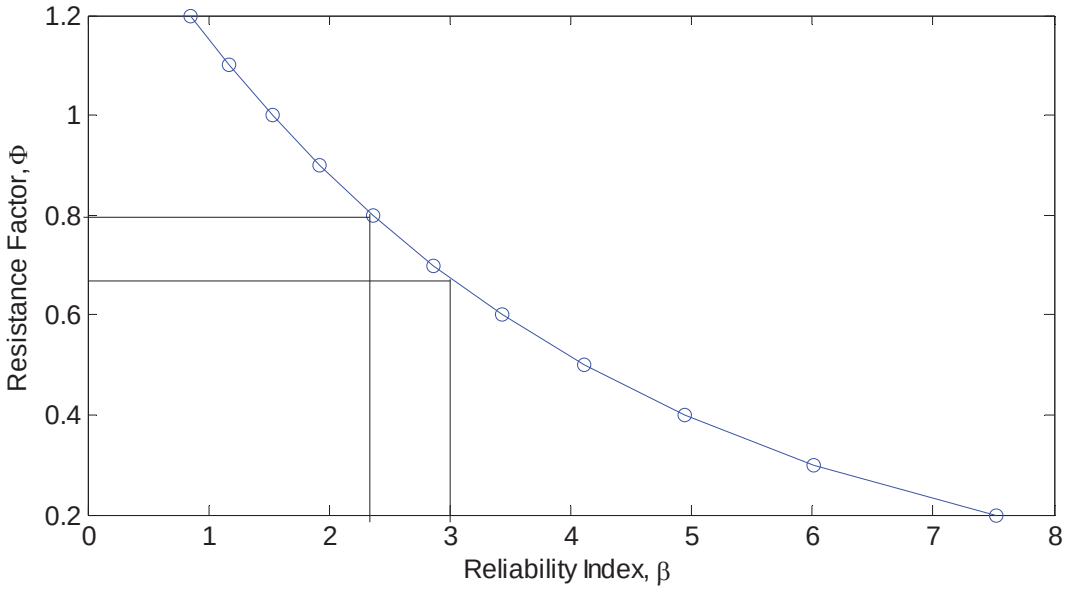


Figure H-M5-f. Resistance factor calibrationfor 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su:Tezaghi, Peck) and using 0.5% D criterion in South of Vietnam

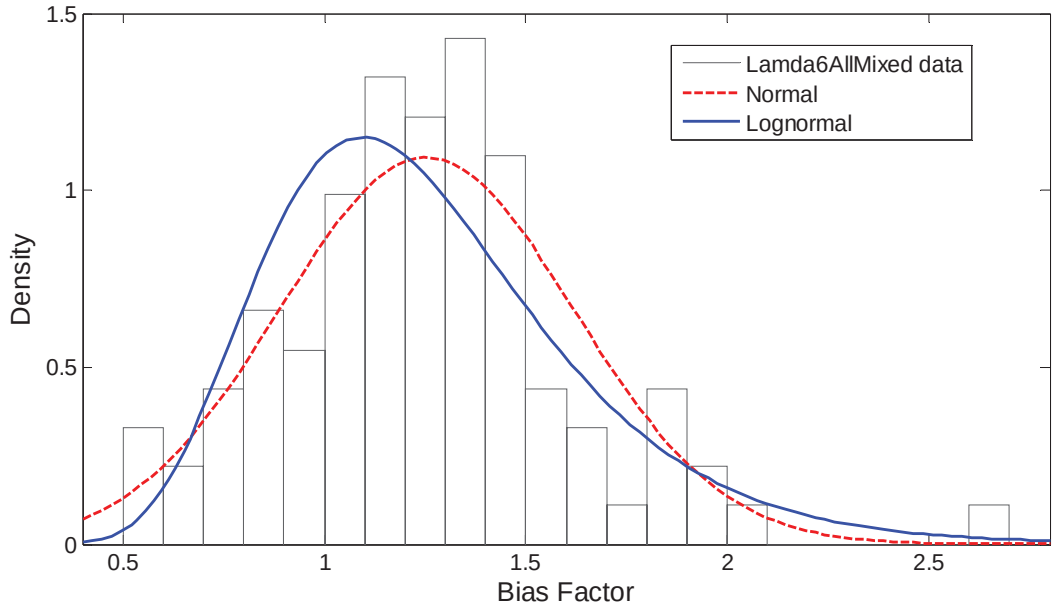


Figure H-M6-a. Histogram and frequency distribution of bias factor λ6 for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in Vietnam

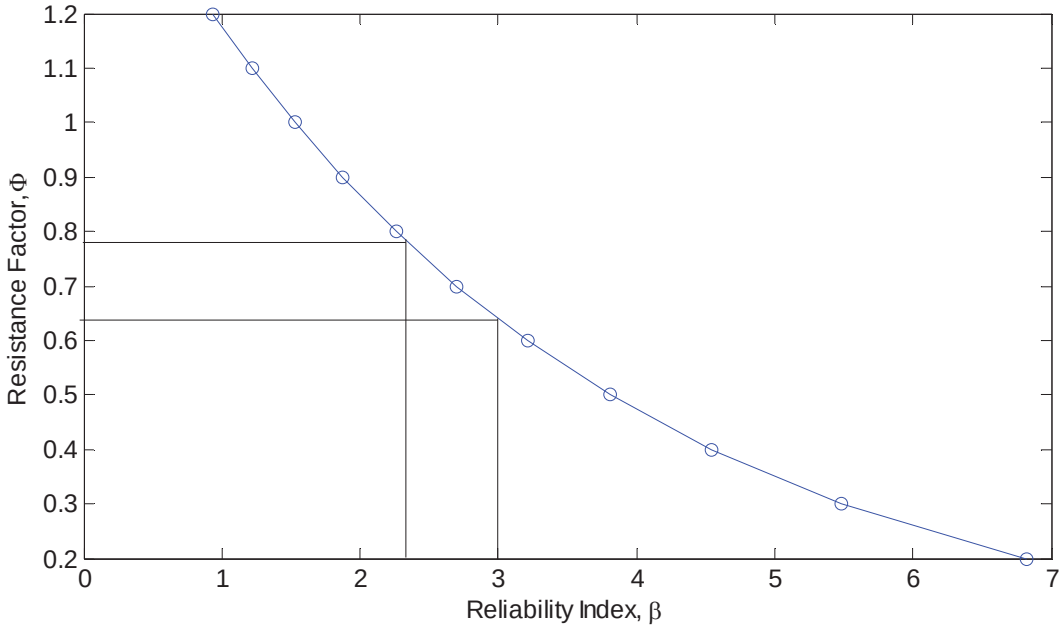


Figure H-M6-b. Resistance factor calibration for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in Vietnam

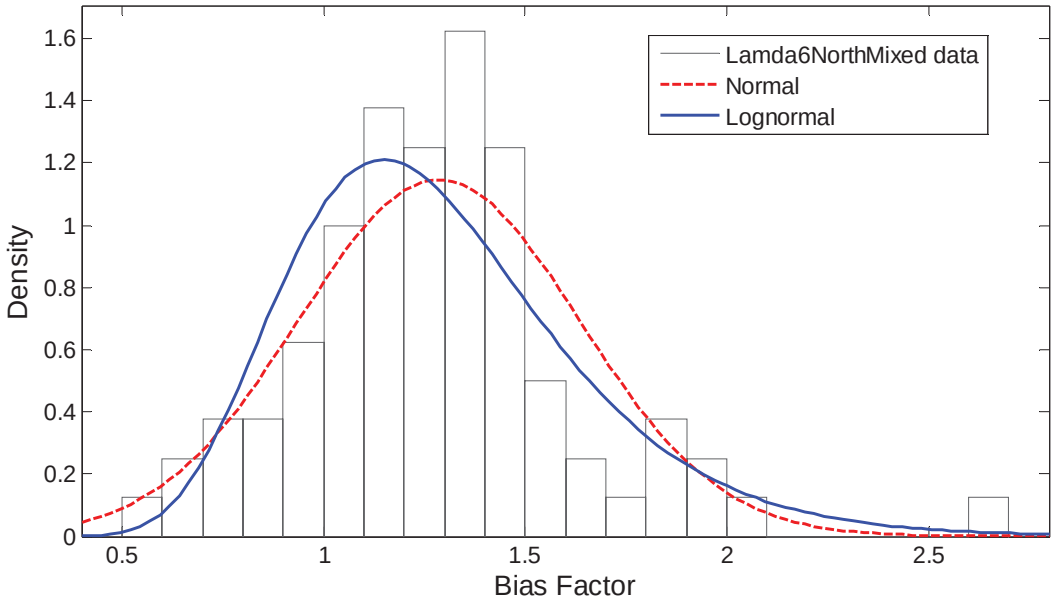


Figure H-M6-c. Histogram and frequency distribution of bias factor λ6 for 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in North of Vietnam

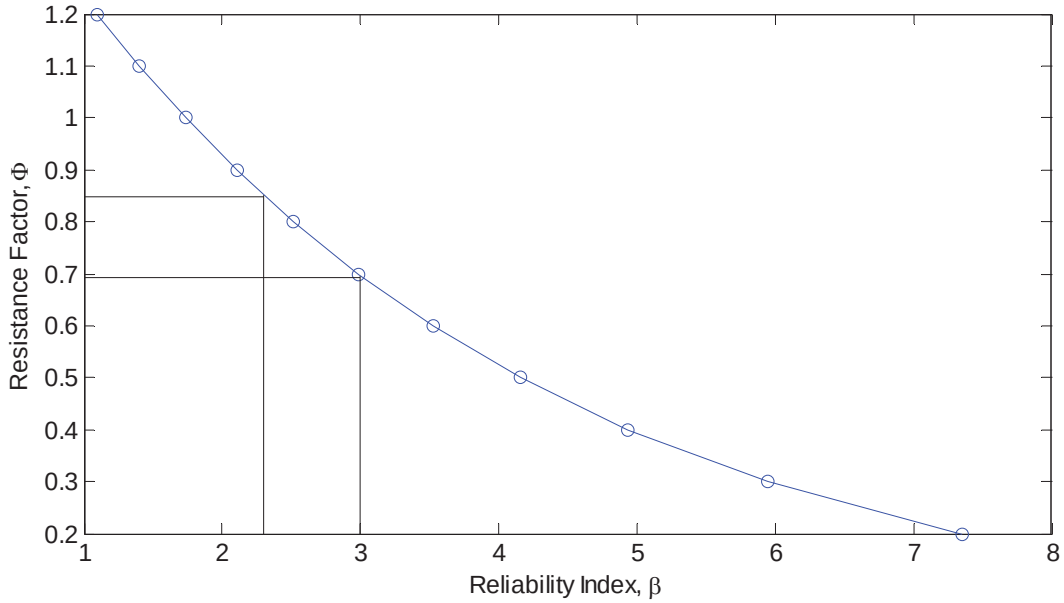


Figure H-M6-d. Resistance factor calibration for 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in North of Vietnam

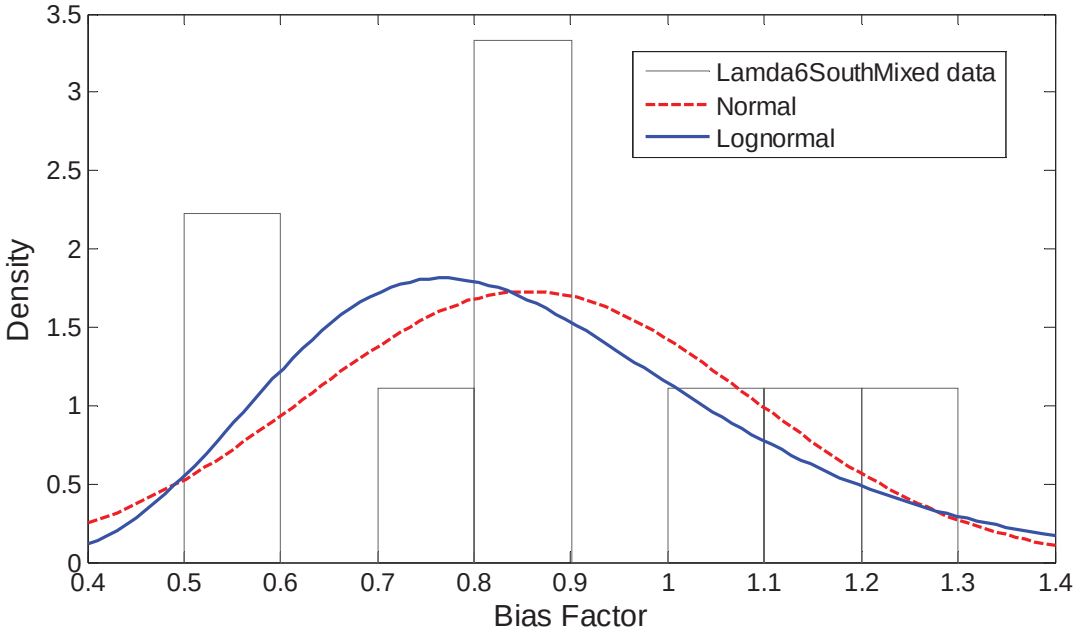


Figure H-M6-e. Histogram and frequency distribution of bias factor λ6 for 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in South of Vietnam

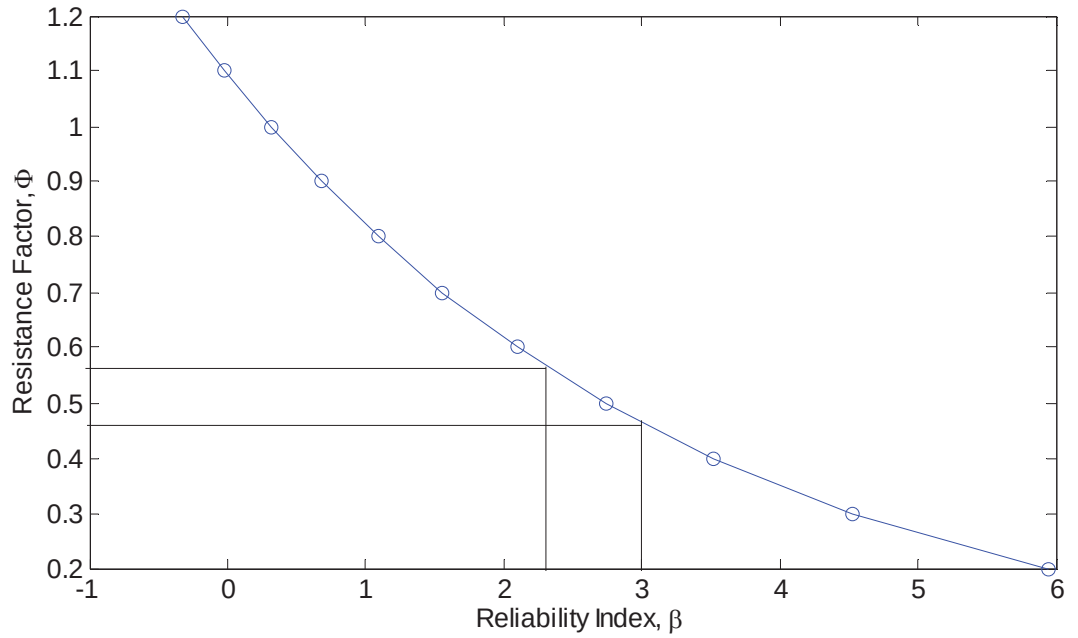


Figure H-M6-f. Resistance factor calibration for 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in South of Vietnam

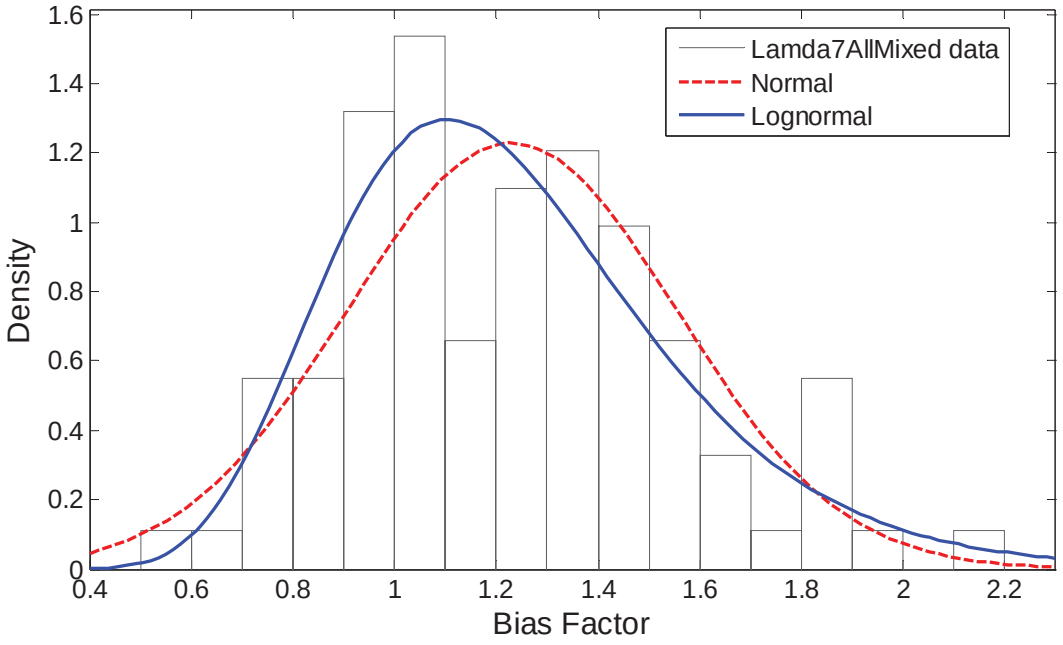


Figure H-M7-a. Histogram and frequency distribution of bias factor λ7 for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in Vietnam

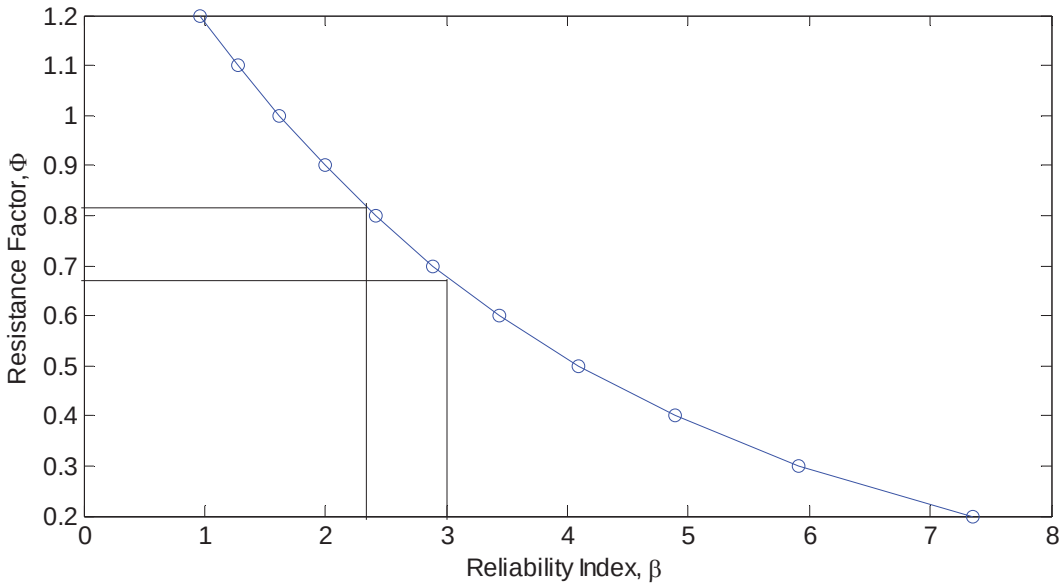


Figure H-M7-b. Resistance factor calibration for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in Vietnam

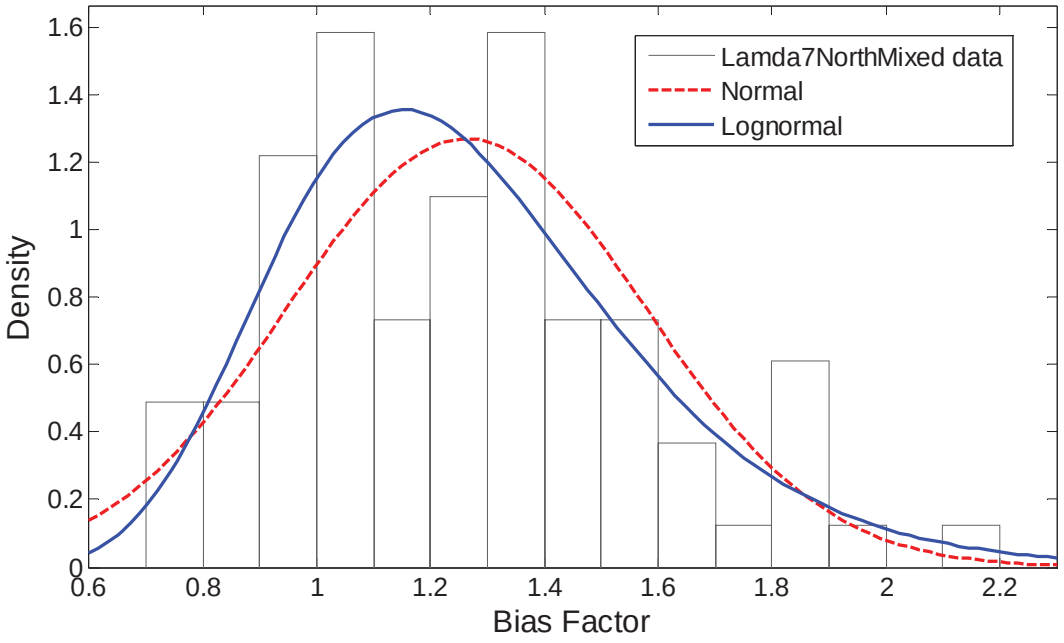


Figure H-M7-c. Histogram and frequency distribution of bias factor λ7 for 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in North of Vietnam

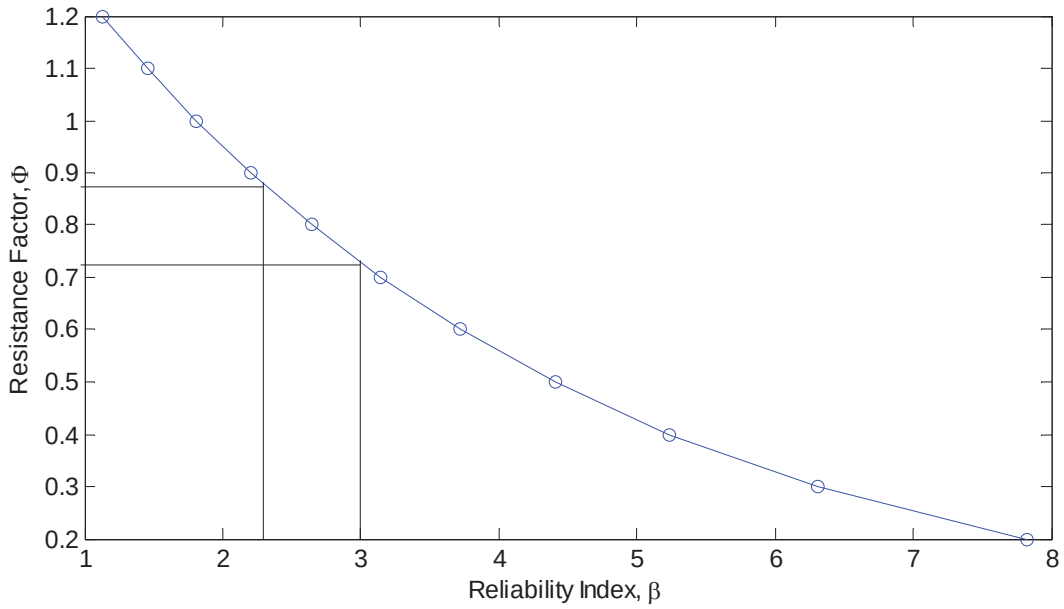


Figure H-M7-d. Resistance factor calibrationfor 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in North of Vietnam

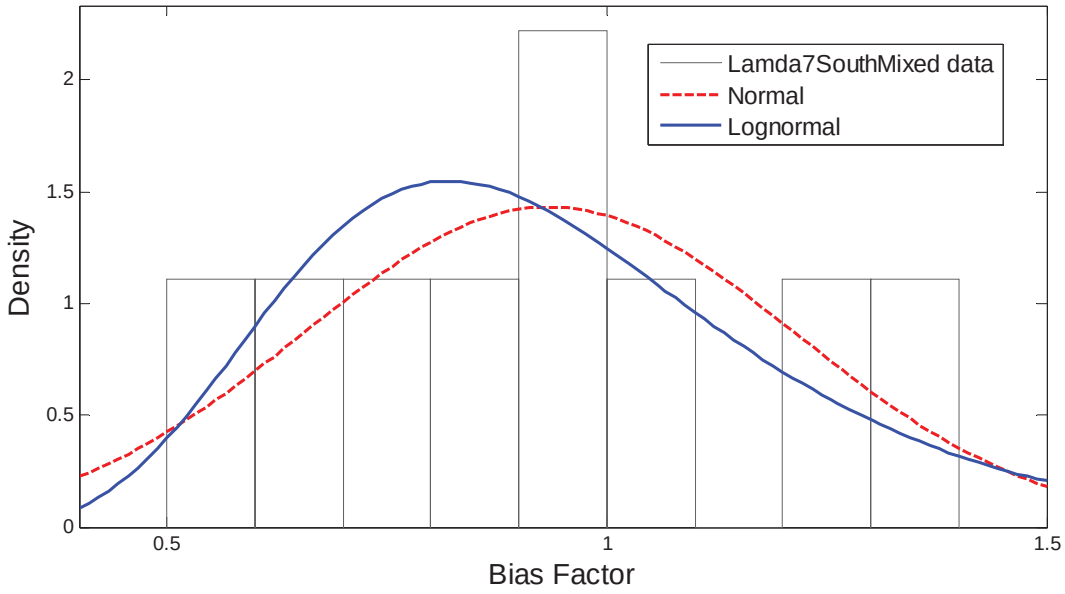


Figure H-M7-e. Histogram and frequency distribution of bias factor λ7 for 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in South of Vietnam

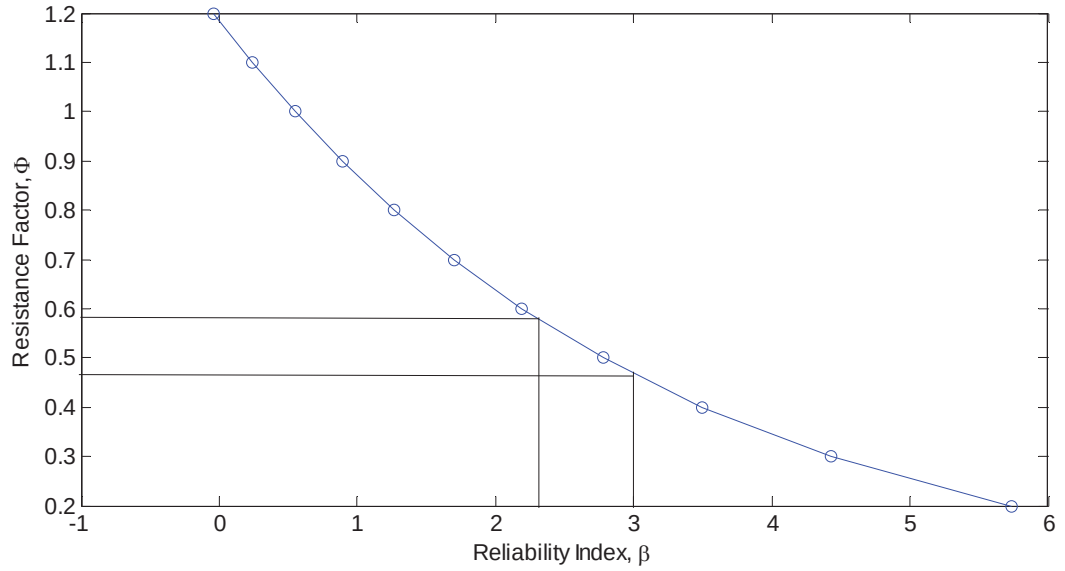


Figure H-M7-f. Resistance factor calibrationor 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Tezaghi, Peck) and using 0.5% D criterion in South of Vietnam

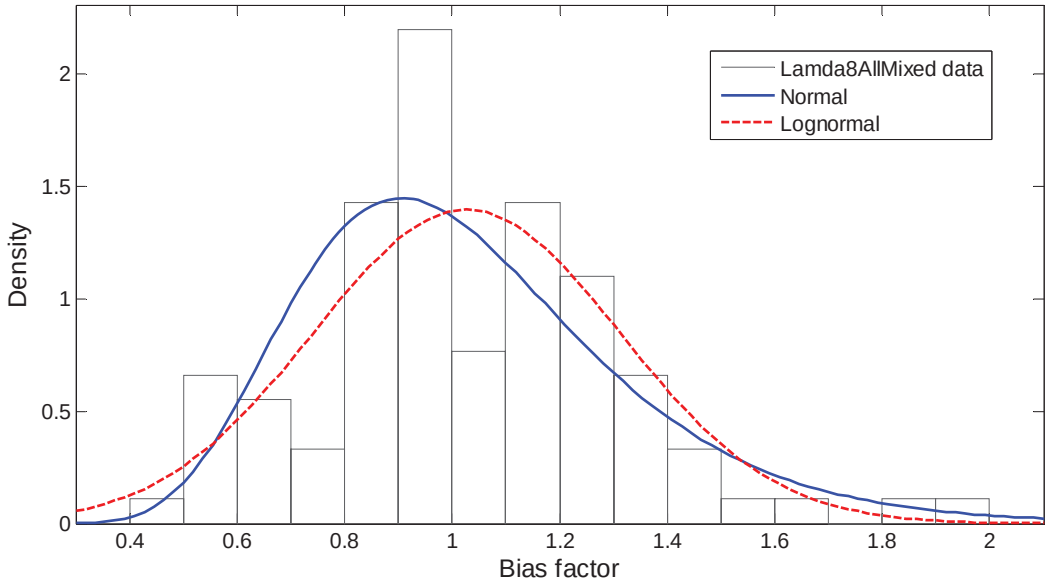


Figure H-M8-a. Histogram and frequency distribution of bias factor λ8 for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in Vietnam

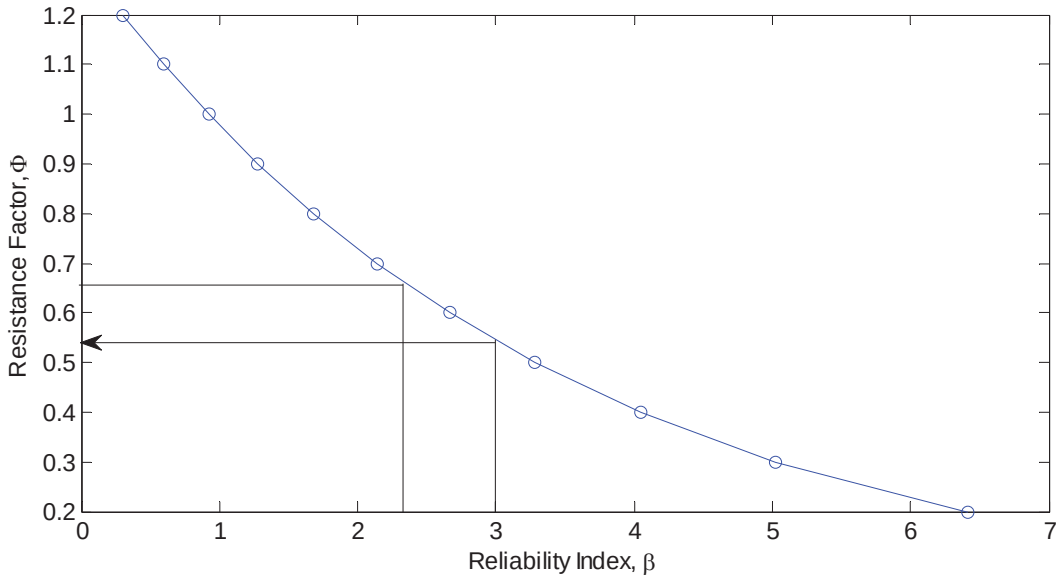


Figure H-M8-b. Resistance factor calibration for 92 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in Vietnam

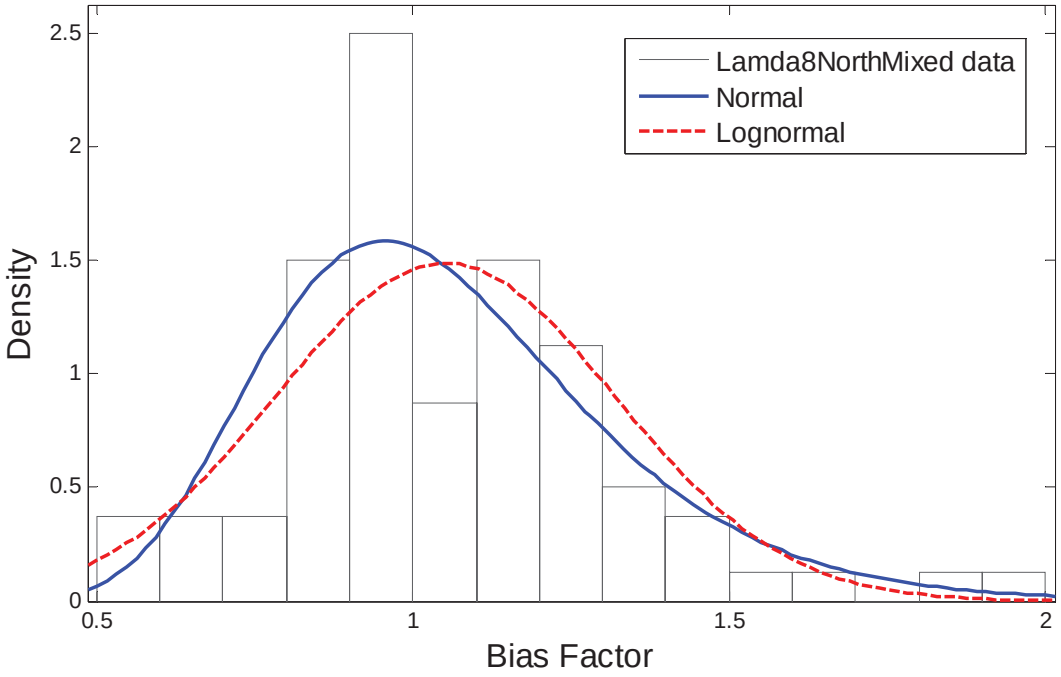


Figure H-M8-c. Histogram and frequency distribution of bias factor λ8 for 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in North of Vietnam

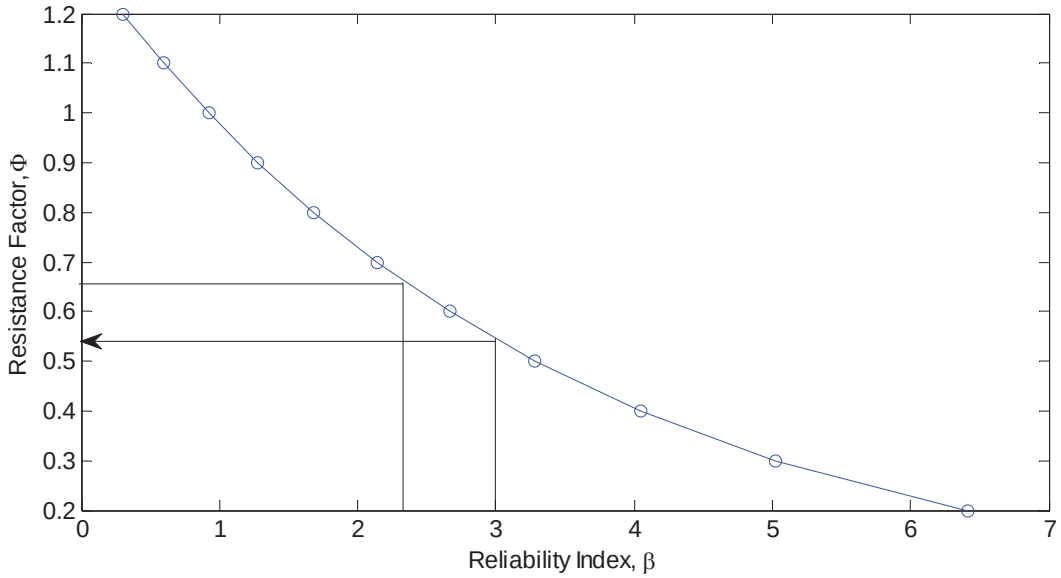


Figure H-M8-d. Resistance factor calibrationfor 80 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in North of Vietnam

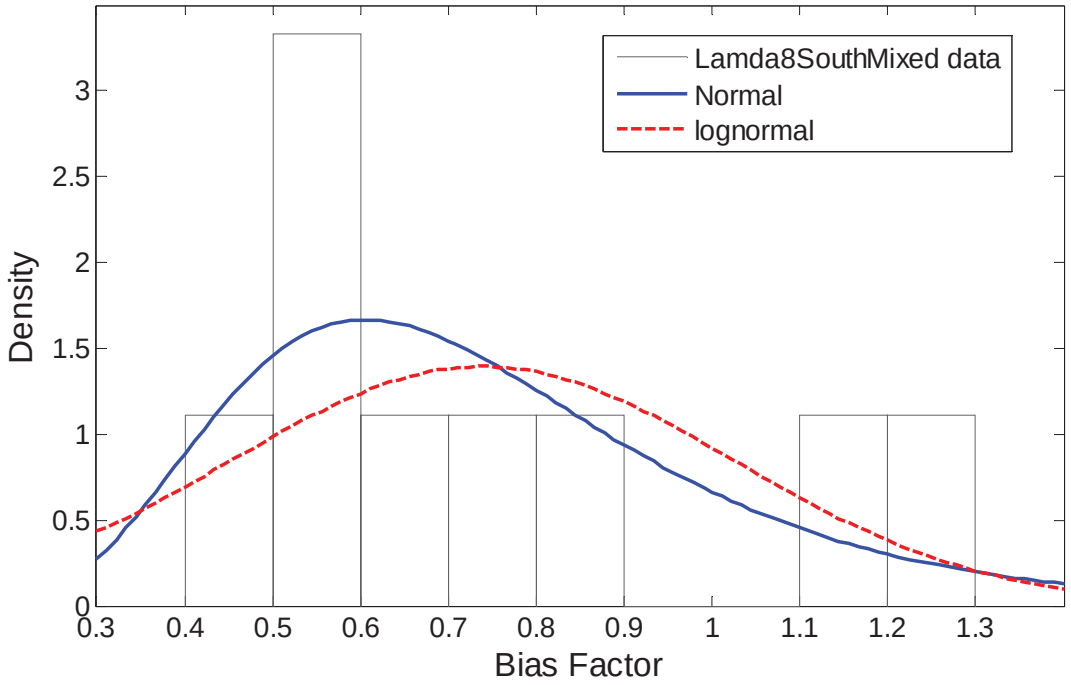


Figure H-M8-e. Histogram and frequency distribution of bias factor λ8 for 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in South of Vietnam

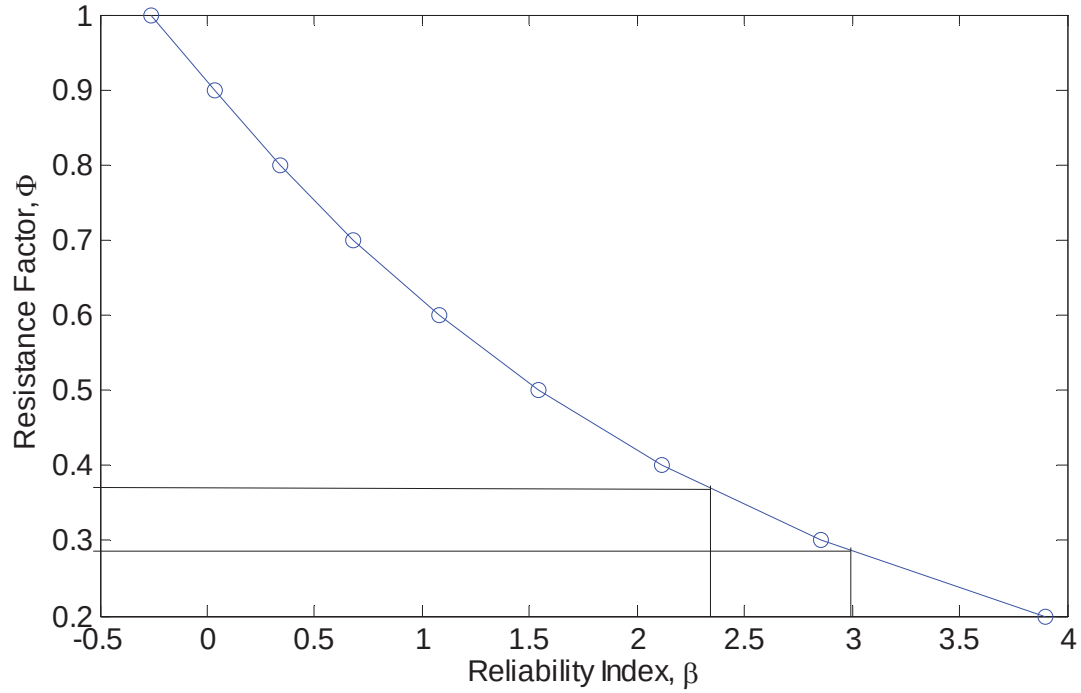


Figure H-M8-f. Resistance factor calibrationfor 10 cases of drilled shaft in Mixed soils using the Reese and Wright method (Su: Hara) and using 0.5% D criterion in South of Vietnam

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